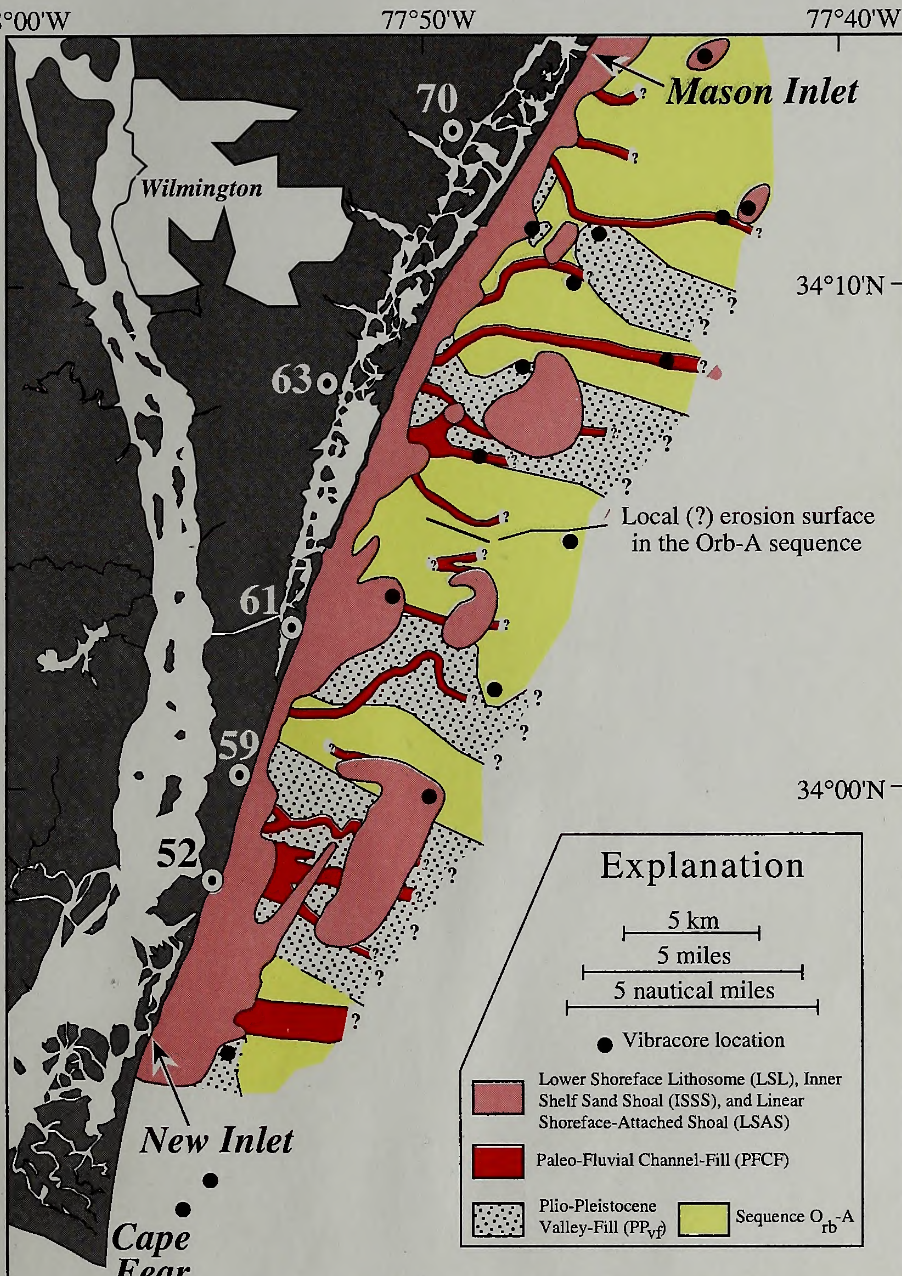
SEISMIC STRATIGRAPHIC FRAMEWORK OF THE INNER CONTINENTAL SHELF: MASON INLET TO NEW INLET, NORTH CAROLINA

by

Stephen W. Snyder, Charles W. Hoffman, and Stanley R. Riggs



BULLETIN 96
NORTH CAROLINA GEOLOGICAL SURVEY
DIVISION OF LAND RESOURCES
DEPARTMENT OF ENVIRONMENT, HEALTH AND NATURAL RESOURCES

The Geological Survey Section examines, surveys, and maps the geology, mineral resources, and topography of the state to encourage the wise conservation and use of these resources by industry, commerce, agriculture, and government agencies for the general welfare of the citizens of North Carolina.

The Section conducts basic and applied research projects in environmental geology, mineral resource exploration, and systematic geologic mapping. Services include identifying rock and mineral samples submitted by citizens and providing consulting services and specially prepared reports to agencies that need geological information.

The Geological Survey Section publishes Bulletins, Economic Papers, Information Circulars, Educational Series and Geologic maps. For a list of publications or more information about the Section, contact the Geological Survey Section, Division of Land Resources, at Post Office Box 27687, Raleigh, North Carolina 27611-7687 or call (919) 733-2423.

Jeffrey C. Reid
Chief Geologist

SEISMIC STRATIGRAPHIC FRAMEWORK OF THE INNER CONTINENTAL SHELF: MASON INLET TO NEW INLET, NORTH CAROLINA

by

Stephen W. Snyder, Charles W. Hoffman, and Stanley R. Riggs

North Carolina Geological Survey

Bulletin 96

1994

Charles H. Gardner, Director and State Geologist

STATE OF NORTH CAROLINA

JAMES B. HUNT, JR., GOVERNOR

DEPARTMENT OF ENVIRONMENT,
HEALTH AND NATURAL RESOURCES
JOHNATHAN B. HOWES, SECRETARY

CONTENTS

ILLUSTRATIONS

Seismic Stratigraphic Framework of the Inner Continental Shelf: Mason Inlet to New Inlet, North Carolina

by

Stephen W. Snyder, North Carolina State University

Charles W. Hoffman, North Carolina Geological Survey

Stanley R. Riggs, East Carolina University

ABSTRACT

An internally-consistent, three-dimensional geologic framework was constructed from 119 km of high-resolution seismic-reflection profile data collected from an inner continental shelf area along the northeast flank of the Cape Fear Cuspate Foreland (CFCF). Preliminary correlations to onshore borehole data and nearby offshore vibracore information depict the following hierarchy of Mesozoic and Paleogene seismic sequences (in ascending order): K_{pd}, a Late Cretaceous sequence correlative to the Peedee Formation; E_{ch}, a middle Eocene sequence equivalent to the Castle Hayne Formation; and O_{rb}-A, an early Oligocene sequence correlative to the lower part of the River Bend Formation. Of these three seismic sequences, only the early Oligocene section crops out on the sea floor in the survey area. This sequence contains a local(?) discontinuity surface which tentatively has been interpreted to be a diastem, but it may represent a more regional unconformity surface separating the mapped Oligocene section into two sequences.

Several distinct, mappable, but discontinuous stratigraphic units also occur in the study area. These lithosomes include Plio-Pleistocene age valley-fill deposits (PP_{vf}) which occur in broad (greater than 5 km) incised valleys cut 20 to 25 meters into the Oligocene section. Near-surface, Quaternary age stratigraphic units include the Lower Shoreface Lithosome (LSL), Linear Shoreface-Attached Shoals (LSAS), Inner Shelf Sand Shoals (ISSS), and Paleo-Fluvial Channel-Fill (PFCF) deposits.

INTRODUCTION

This report is an interim product for a multi-year research project being conducted cooperatively by the North Carolina Geological Survey, the U.S. Geological Survey, and the Department of Marine, Earth and Atmospheric Sciences at North Carolina State University. A primary objective of the program is to complete a preliminary heavy-mineral resource assessment of the inner continental shelf area surrounding the Cape Fear Cuspate Foreland (CFCF) (Figure 1). This resource assessment program is relying chiefly on three types of existing data—shallow-penetrating vibracores, high-resolution seismic reflection profiles, and archived borehole samples with geophysical and lithologic logs (Figure 2).

The seismic data are being used to construct an internally-consistent stratigraphic framework for the entire CFCF project area. Lithologic and biostratigraphic data obtained from vibracores and correlative onshore boreholes are being integrated to elevate the emerging seismic stratigraphic framework to a comprehensive, three-dimensional geologic framework. Once established, this framework will be used to evaluate the potential for heavy-mineral resources within specific stratigraphic units mapped in the offshore Economic Exclusive Zone via the seismic data base. Heavy-mineral data accumulated through detailed analyses of the available vibracores will be evaluated on a unit-by-unit basis based on the mapped stratigraphic position of the vibracore material.

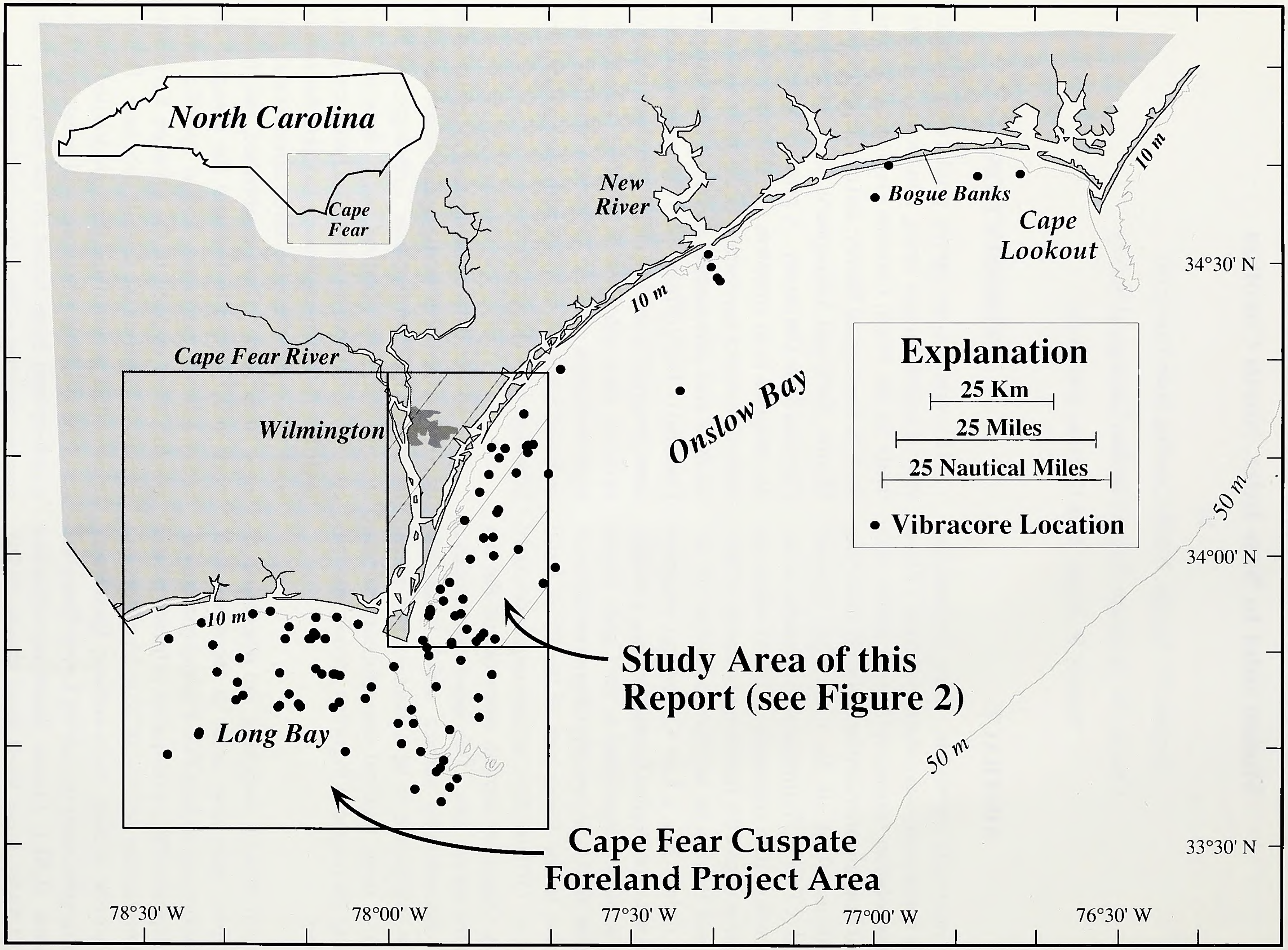


Figure 1. Location map of present study area, its relationship to the Cape Fear Cuspate Foreland project area, and their relationship to the North Carolina continental shelf embayments of Onslow Bay and Long Bay.

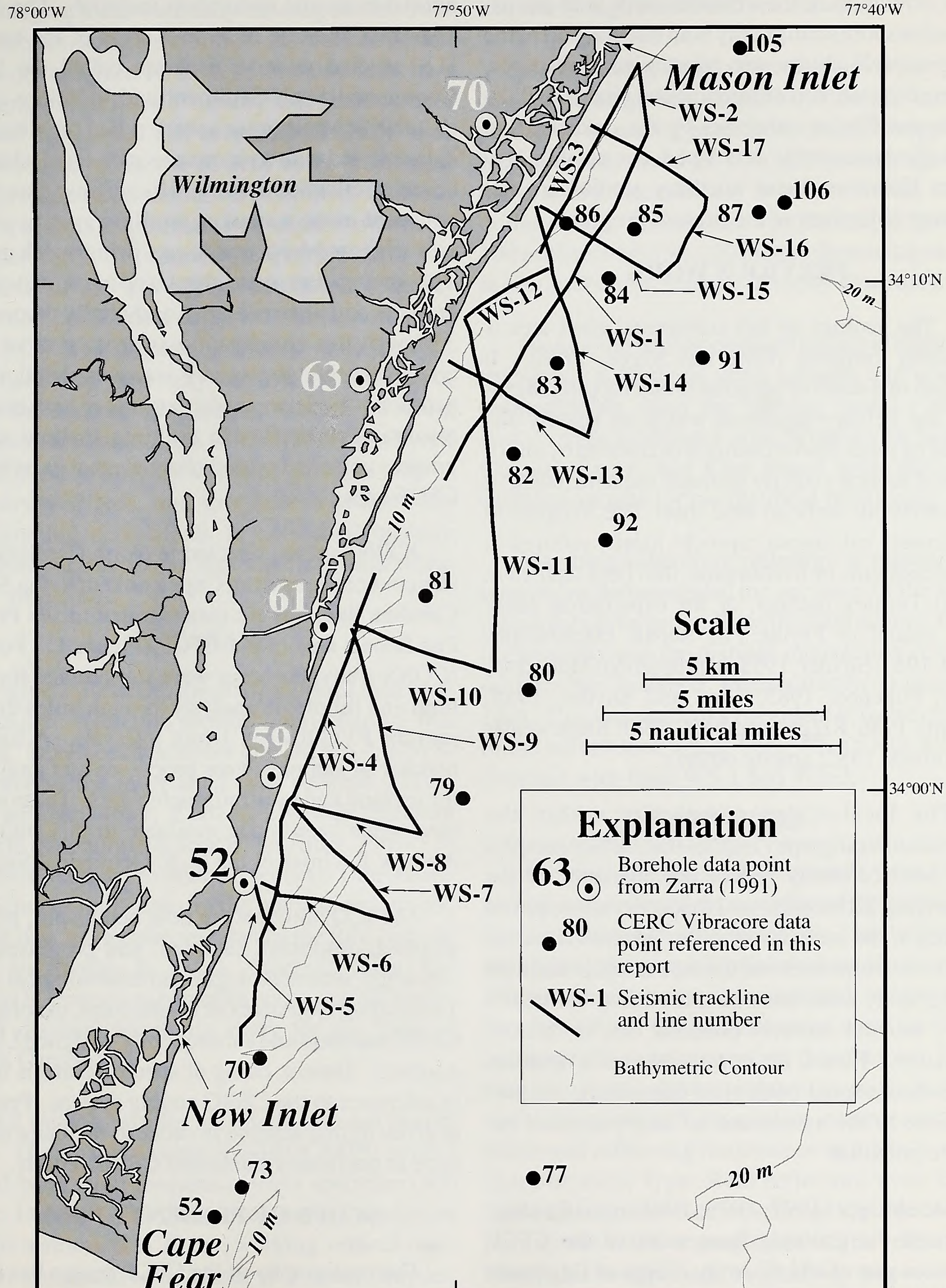


Figure 2. Locations of seismic reflection profiles (labeled lines), continental shelf vibracores (solid circles), and onshore borehole sites (bull's eyes) discussed in this report.

Correlation of the offshore work with the ascribed onshore stratigraphy is an integral part of the study as well. Numerous other mineral resource, water resource, and environmental studies will be made possible or enhanced by the database and geologic framework developed out of this program. However, these ancillary studies are not primary objectives of the present program.

PREVIOUS WORK

The geology of this continental shelf area is relatively complex (Hine and Riggs, 1986). It consists of a series of irregularly outcropping Mesozoic and Tertiary sequences which are heavily dissected by relict fluvial channels or covered by one or more of several younger geologic units including: a discontinuous surficial sand sheet; late Neogene to Quaternary calcareous caprocks locally referred to as hardbottoms or livebottoms; thin (less than 10 m thick) Tertiary outliers; or the cape-retreat sand/ rock massif of Frying Pan Shoals (Meisburger, 1979; 1981; Snyder, 1982; in prepartion; Matteucci, 1984; Popenoe, 1985; Hine and Snyder, 1985; Mearns, 1986; Riggs and others, 1990; Blackwelder and others, 1982; among others).

The local-scaled complexity within the subbottom stratigraphy implies that surface samples may not accurately reflect the character of the underlying lithologies, and that cores are required to sample the underlying units. Moreover, accurate correlations between the core samples and host stratigraphic units must be established before the heavy mineral resource potential can be reliably evaluated. Hence, the construction of a detailed, three-dimensional geological framework is a prerequisite to the assessment of heavy-mineral resource potential.

Meisburger (1977; 1979; 1981) initially characterized the geologic framework of the CFCF region as part of a U. S. Army, Corps of Engineers Coastal Engineering Research Center (CERC) project focused on the delineation of offshore sand and gravel resources suitable for use as beach nourishment and restoration material. The Cape Fear area was one of several areas of the eastern U.S. studied under a program called the Inner Continental Shelf Sediment and Structure study (ICONS). Meisburger's work relied on vibracore data coupled with a reconnaissance-level, shallow seismic-reflection survey. His seismic data were collected using a sparker profiling system which was triggered by a spark-gap firing mechanism. The analog data were displayed on a wet-paper recorder and were not taped or digitally processed. Although this equipment was near "state-of-the-art" at the time the survey was completed, these data are of moderate quality and not of high enough resolution to depict the multiple shallow stratigraphic units and buried channels that exist in the CFCF area.

ICONS cores collected in North Carolina waters cover an area from Cape Lookout to the South Carolina line, but are concentrated in the Frying Pan Shoals area of the CFCF (Figure 1). For the ICONS study, the cores were subsampled for textural and lithologic analysis through holes drilled into the PVC liner at 1-foot intervals. A limited number of samples were processed and analyzed for textural and biostratigraphic data. These cores have since been made available to this study by Andrew E. Grosz of the U. S. Geological Survey.

The ICONS cores are now being split, photographed, described, sampled, and processed for lithologic, sedimentologic, and mineralogical data. Two coding systems exist for the cores, the original CERC numbers and subsequently-assigned USGS numbers. Herein, citing of specific cores is made in reference to the CERC coding system. Priority is given to that scheme in order to facilitate reference to previously published CERC reports.

SCOPE OF PRESENT STUDY

The stratigraphy of the CFCF region has been described as complex. Moreover, the existing geologic framework rendered by past seismic surveys was completed before high-resolution seis-

mic imaging tools were fully-developed. In order to establish accurate correlations between each vibracore analyzed for heavy minerals and its host stratigraphic unit, and thereby facilitate a more rational assessment and inventory of heavy-mineral resources from the ICONS cores, additional stratigraphic information were required. This report represents a significant first step towards meeting that need. It presents the interpretation and synthesis of 119 km of high-resolution, seismic-reflection profile data collected from a portion of the CFCF area (Figures 1 and 2). The data set establishes an internally-consistent, subbottom, three-dimensional stratigraphic framework along the northeast flank of the CFCF. This framework is sufficient to develop a surface geologic map of the surveyed area, and to establish preliminary stratigraphic correlations to published onshore borehole stratigraphies and existing continental shelf vibracores.

DATABASE

Figure 2 illustrates the distribution of intersecting seismic-reflection profiles interpreted for this report. Seventeen tracklines labeled WS-1 to WS-17 traverse the inner shelf area between Mason Inlet and New Inlet. Collectively, they represent 123 km of continuous seismic profiling. Only 119 km were reduced to seismic sections (line-drawings) due to limitations in the navigation data set. These data were collected aboard the R/V Nitro in 1978 by Stanley R. Riggs, Albert C. Hine, and Daniel R. Pearson as part of an ocean outfall/wastewater disposal feasibility study for the State of North Carolina.

All seismic profiles are single-channel analog data. The seismic source (UNIBOOM™) emits a broad-band, high-frequency, wave spectrum (400 Hz to 14 kHz). The theoretical vertical resolution of this instrument is 20 cm; working vertical resolution was found to be closer to 1 meter (Snyder, 1994). Pulse generation was triggered by a mercury-vapor ignatron. Firing rates varied, but were always faster than 0.7 seconds in order to maintain extremely high horizontal resolution.

The incoming signal was collected on an eight-element hydrophone, amplified, filtered, and recorded on an analog graphic recorder. Sweep rate was generally fixed at 100 milliseconds (2-way travel time); occasionally it was switched to 50 milliseconds. Penetration was limited to the first 100 milliseconds (90-100 meters depending on the *in situ* subbottom seismic-velocity structure).

Navigation was determined by line of sight and triangulation methods using azimuth and sextant measurements from the moving vessel. Many easily visible landmarks in the Wrightsville Beach, Carolina Beach, and Kure Beach areas provided excellent targets for navigational positioning.

Matching subbottom reflectors at mapped intersections demonstrated the accuracy of the navigation data to be generally within 600 meters. Only occasionally was the mapped intersection site offset from the "matched" intersection by as much as 1 km. This was particularly evident in the north end of the survey area where lines WS-15 and WS-17 intersect with lines WS-1 and WS-3.

METHODS

The raw graphic seismic records were interpreted and reduced to a series of stratigraphic line-drawings (seismic sections). The method of translating the graphic seismic records to stratigraphic line-drawings is outlined in detail in Snyder (1994). Three basic steps were involved in interpreting and presenting this data set. First, the raw seismic data were photocopied, studied, and subbottom reflectors were interpreted to be either real reflecting horizons or an artifact (multiple) of some type. Real reflectors were highlighted using a four-color scheme to subjectively portray the relative amplitude of the reflectors. Next, the interpreted, marked-up photocopies were systematically reduced to stratigraphic line-drawings by hand-digitizing each highlighted seismic reflector.

The digitizing exercise used a large-format digitizing tablet (4 feet by 5 feet) and microcomputer workstation. Software developed by the first author was used to rectify horizontal and vertical scaling. Digitized reflector information was stored in a four-dimensional array (latitude, longitude, depth below sea-level in milliseconds, and reflector amplitude color code). Finally, hard copies of the digitized data were plotted on a large-format drafting plotter at a predetermined vertical exaggeration of 100:1. Color coding on these plots reflects relative amplitudes (color plots only); for black and white drafts, each color was assigned a different line weight.

The seismic sections were imported to a Macintosh™ graphics program where they were annotated and sized for publication as stratigraphic line-drawings. Time events corresponding to mapped navigation positions are shown at the bottom of each seismic section and in the map view of the track line. Reflectors identified as unconformities are identified with Greek letters. These unconformity surfaces and the intervening stratigraphic sequences are presented and fully discussed in later sections of this report.

The vertical meter scale shown in all seismic profile and stratigraphic line drawings is an approximate scale. It was calculated using a water-column seismic velocity of 1500 meters/second, and a second velocity of 1700 meters/second for subbottom travel-times (an approximately 13 percent increase). Seismic velocities recorded in unconsolidated to semi-consolidated siliciclastic and carbonate stratigraphic sections range from 1600-2300 meters/second (Sheridan and others, 1966; Grow and Markle, 1977; Buffler and others, 1979; 1981; Grow and others, 1979; Ebeniro and others, 1986; Slowey and others, 1989). More typically, the velocity range for unconsolidated siliciclastics is in the 1650-1750 meters/second range (Snyder, 1994). Meisburger (1979) used a linear subbottom velocity of 1693 meters/second for time-to-depth conversions when interpreting the ICONS data set from the CFCF area.

STRATIGRAPHIC FRAMEWORK

The intersecting seismic profiles present a three-dimensional, subsurface data set from which reflecting stratal horizons can be mapped (Figure 3). These data provide the framework for identifying discontinuity surfaces, and then deciphering regional from local unconformity surfaces. Regional unconformities are defined as those discontinuity surfaces which can be carried throughout the subbottom seismic network.

All regional unconformities were traced from the subsurface to their intersection with the sea floor. The reflector/unconformity outcrop positions were then mapped in order to construct the geologic map illustrated in Figure 4. The map depicts the spatial distribution of all the outcropping stratigraphic units identified in the survey area.

Mapped Units

Stratigraphic analyses of the seismic reflection data identified several distinct and mappable units. The relative chronostratigraphic position for each mappable unit is given in Figure 5. The time-stratigraphic position is based entirely on the law of superposition as defined in the seismic data. The interpreted relationship of these sequences and lithosomes[1] to stratigraphic units previously mapped or defined in the literature is portrayed in Figure 6.

Only two unconformity surfaces were traced throughout the entire study area via the network of intersecting subsurface seismic sections. These unconformities are interpreted to be correlative to surfaces α and β_1 of Snyder (1982), although no direct tie-lines to the seismic network of Snyder (1982) are available to verify this interpretation. Unconformity surfaces α and β_1 form the bound-

[1] The term "lithosome" was introduced by Wheeler and Mallory (1956) to describe a vertically and laterally segregated body of sediment deposited under nearly uniform physicochemical conditions. It is used here to refer to "spatially-segregated parts of a genetically-related body of sedimentary deposits" (Moore, 1957, p. 1787-1788.).

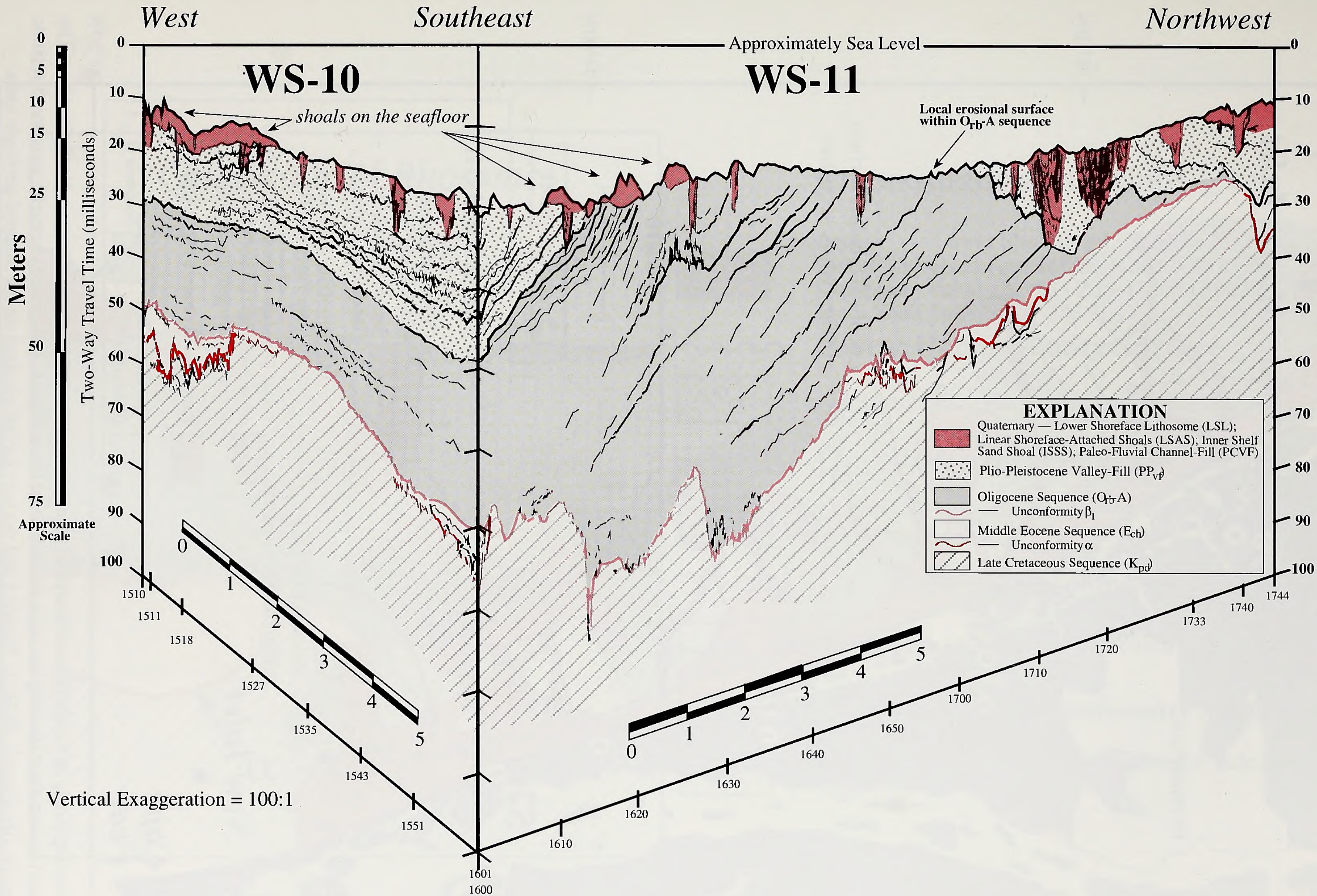


Figure 3. Two intersecting seismic sections (WS-10 and WS-11) presented as a three-dimensional diagram to illustrate the continuous nature of the subbottom data set which facilitated detailed outcrop/subcrop mapping.

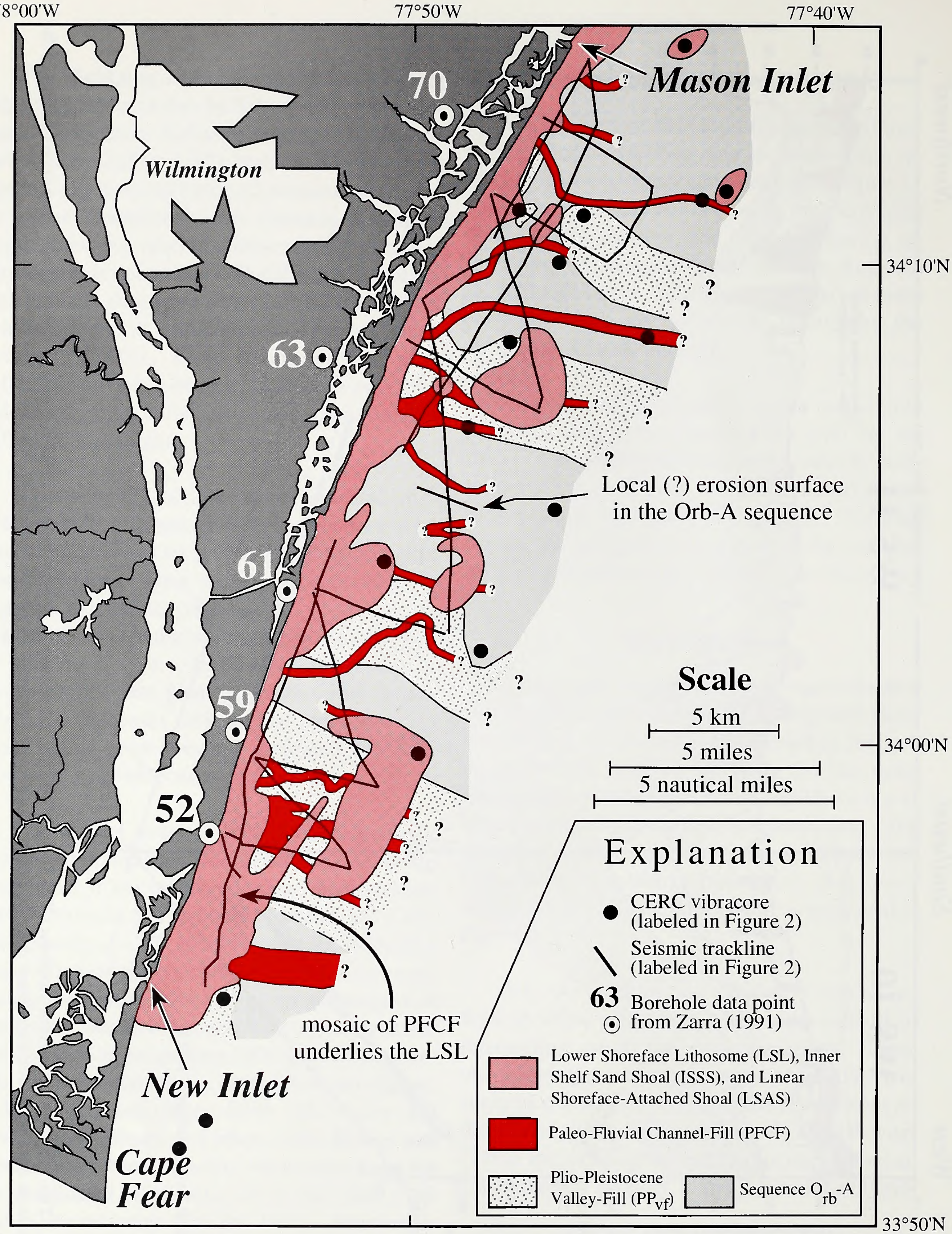


Figure 4. Geologic map of the shoreface through inner continental shelf area off Wilmington, North Carolina. The data used to construct the map are also illustrated (refer to Figure 2 to identify specific numbered seismic sections or vibracores). Refer to Figure 5 and the text for information on the mapped geologic units.

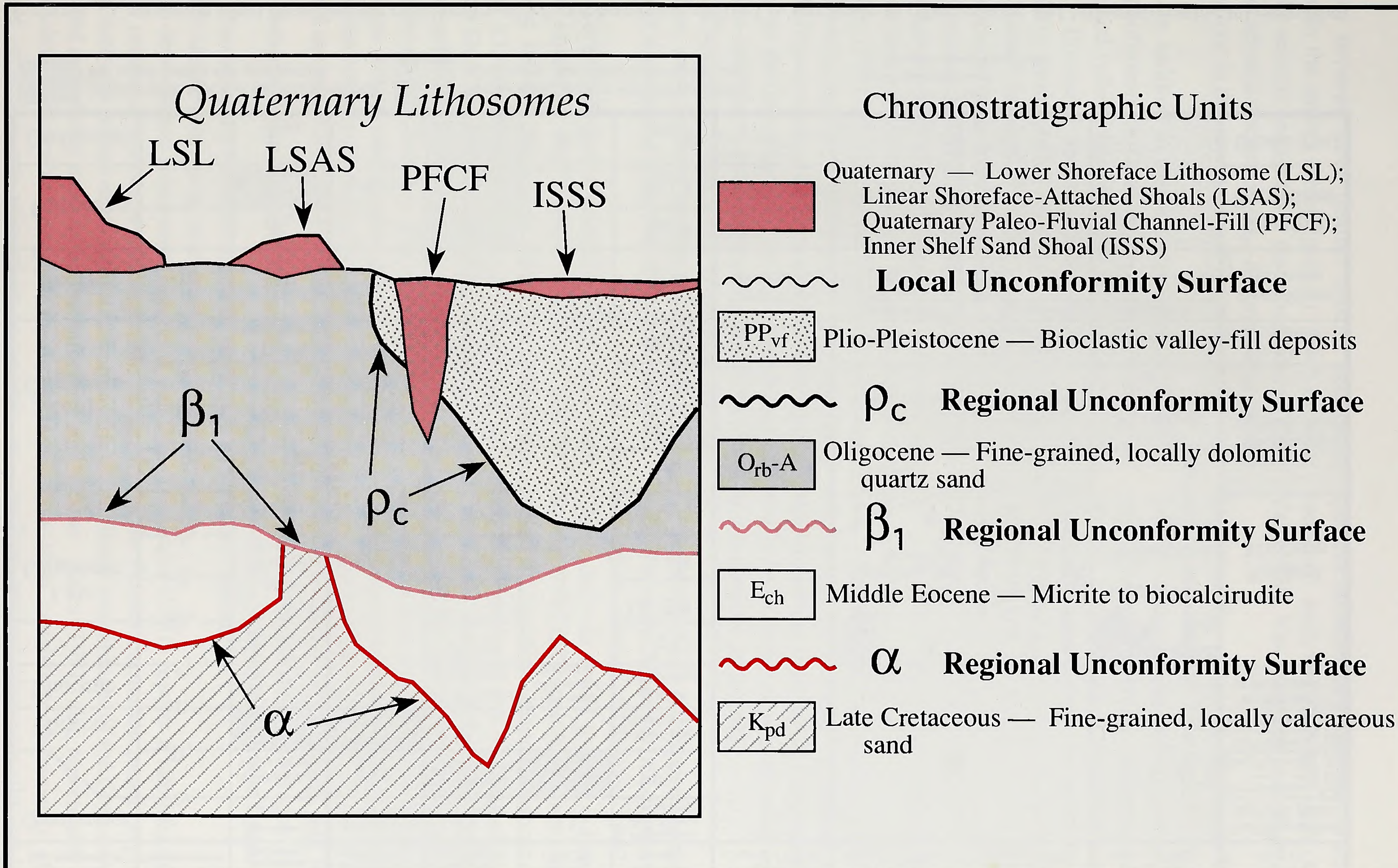


Figure 5. Chart depicting the physical stratigraphic relationships (left panel) and relative time-stratigraphic relationships (right panel) of the geologic units and related unconformity surfaces defined and mapped in this study.

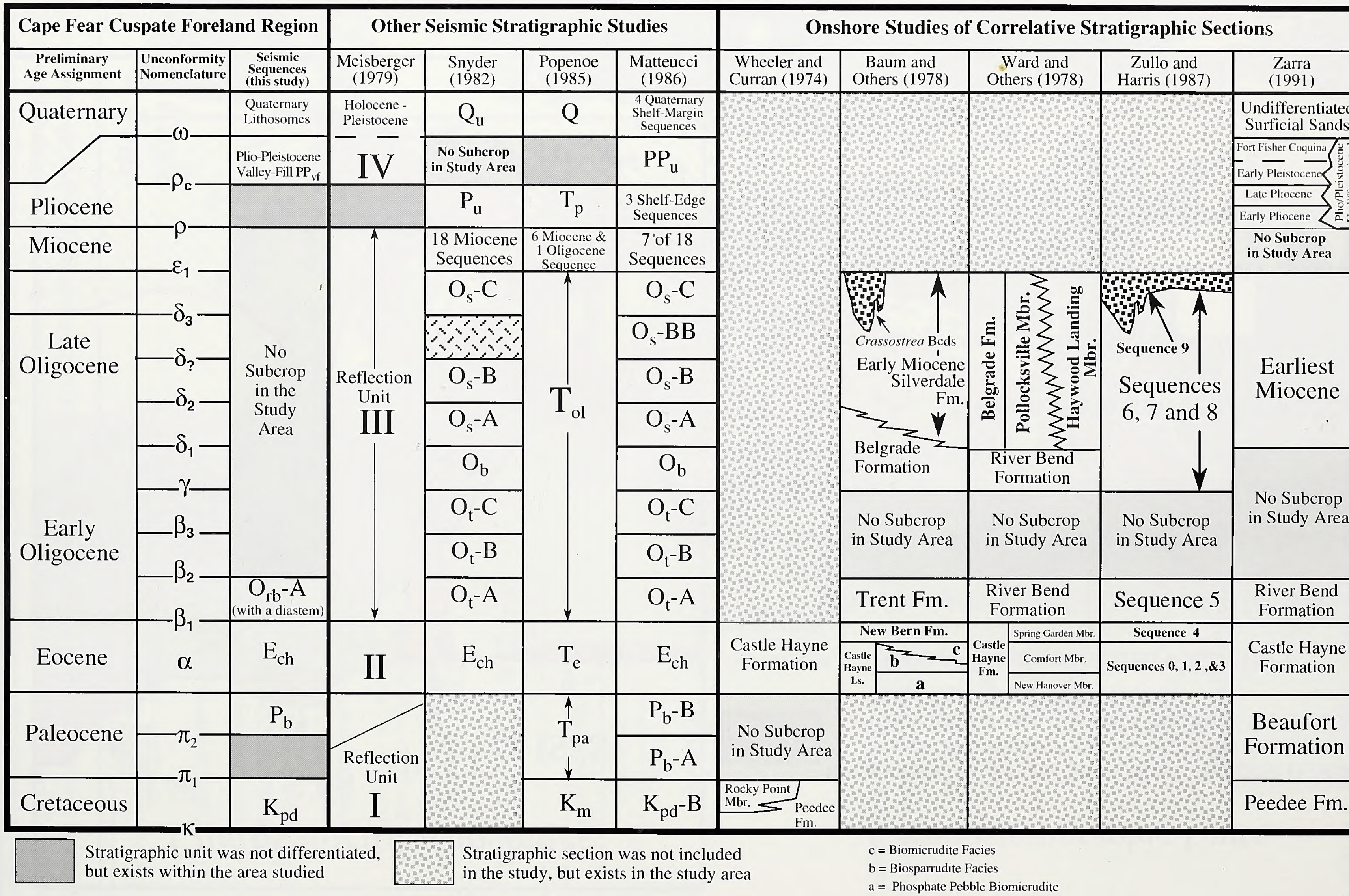


Figure 6. Correlation chart depicting the relationship of seismic sequences defined in this study to other seismic and lithostratigraphic investigations within the Cape Fear cuspate foreland region. Preliminary age assignments are in reference to the seismic sequences defined in this study and are based on extraploations to published biostratigraphic assignments from correlative vibracore or land-based samples.

aries between three distinct seismic sequences within the survey area (Figure 5). Each of these three seismic sequences is discussed below. Only one seismic sequence (O_{rb}-A) crops out on the seafloor in the survey area (Figure 4).

In addition to the two continuous subbottom unconformity surfaces (α and β_1), several large incised valleys were mapped via the seismic data set. Erosional unconformities defining channel wall(s) were labeled ρ_c on all seismic sections (Figures 7 through 23). The relative stratigraphic position of these features is illustrated in Figure 5. Preliminary correlations to the onshore borehole stratigraphy of Zarra (1991) and the vibracore data described in Meisburger (1979) and Hoffman and others (1991) all indicate the valley-fill is Pliocene to Pleistocene in age. Meisburger (1979) and Zarra (1991) have referred to this unit as Plio-Pleistocene due to the presence of a mixed assemblage of micro- and macro- fossils indicative of both Pliocene and Pleistocene faunal zones. Following this precedent, these features are herein referred to as the Plio-Pleistocene Valley-Fill (PP_{vf}) lithosome.

Several distinct Quaternary lithosomes were also identified and mapped (Figures 4 and 5). These include the Lower Shoreface Lithosome (LSL); Linear Shoreface-Attached Shoals (LSAS); Inner Shelf Sand Shoals (ISSS); and Paleo-Fluvial Channel-Fill (PFCF) deposits. They are all surface or near-surface features; and, due to their discontinuous nature, the relative chronostratigraphic position between these four Quaternary lithosomes could not be determined from the seismic data.

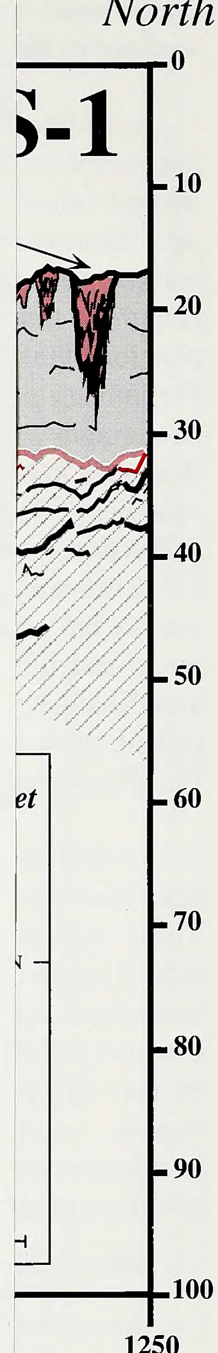
Seismic Sequences and Unconformities

Unconformity surfaces α and β_1 were used to subdivide the subbottom stratigraphic section into three depositional sequences (Figures 5 and 24). Each sequence represents a conformable package of genetically related strata separated from overlying and underlying strata by an unconformity surface which is mappable throughout the survey area. These sequences are referred to as seismic sequences because they were identified via seismic sequence analysis (Mitchum and others, 1977; Vail, 1986; Van Wagoner and others, 1988).

Sequence K_{pd} Sequence K_{pd} underlies the entire survey area (Figures 7 through 23). It consistently exhibits a transparent (reflection-free) seismic facies. The reflection-free character may be due to one or a combination of the following factors: (1) this stratigraphic section lies below the penetration limits of higher-frequency waveforms and therefore prevents any imaging of subtle internal reflectors; (2) a significant loss of seismic energy occurs immediately above this seismic sequence due to the high reflection coefficient of the overlying unconformity surface (that is, α is a high-amplitude reflector); or (3) K_{pd} consists of a non-variant lithofacies. Preliminary correlations indicate this later possibility to be likely; therefore the sequence would be expected to possess relatively homogeneous acoustic properties.

Sequence K_{pd} is not exposed on the seafloor of the survey area. However, it has been traced in the subsurface westward (Snyder, 1982; Matteucci, 1984), and was found to crop out in Long Bay. Snyder (1982) extrapolated its inner-shelf outcrop belt to stratigraphies mapped onshore and inferred that this sequence was equivalent to the Upper Cretaceous Peedee Formation (North Carolina Geological Survey, 1985). Correlations between the seismic data set presented in Figures 7 through 23 and adjacent onshore stratigraphies reported by Zarra (1991) from boreholes 52, 59, 61, 63, and 70 (locations shown on Figure 2, this report) have confirmed the inferred stratigraphic position. Sequence K_{pd} is equivalent to the Upper Cretaceous Peedee Formation.

Zarra (1991) reports a late Maastrichtian age for the Peedee Formation based on planktic foraminiferal assemblages of the *Gansserina gansseri* Zone. Zarra (1991) also reports that the Peedee Formation consists predominantly of a fine- to medium-grained calcareous silty sand with traces



d on the map.

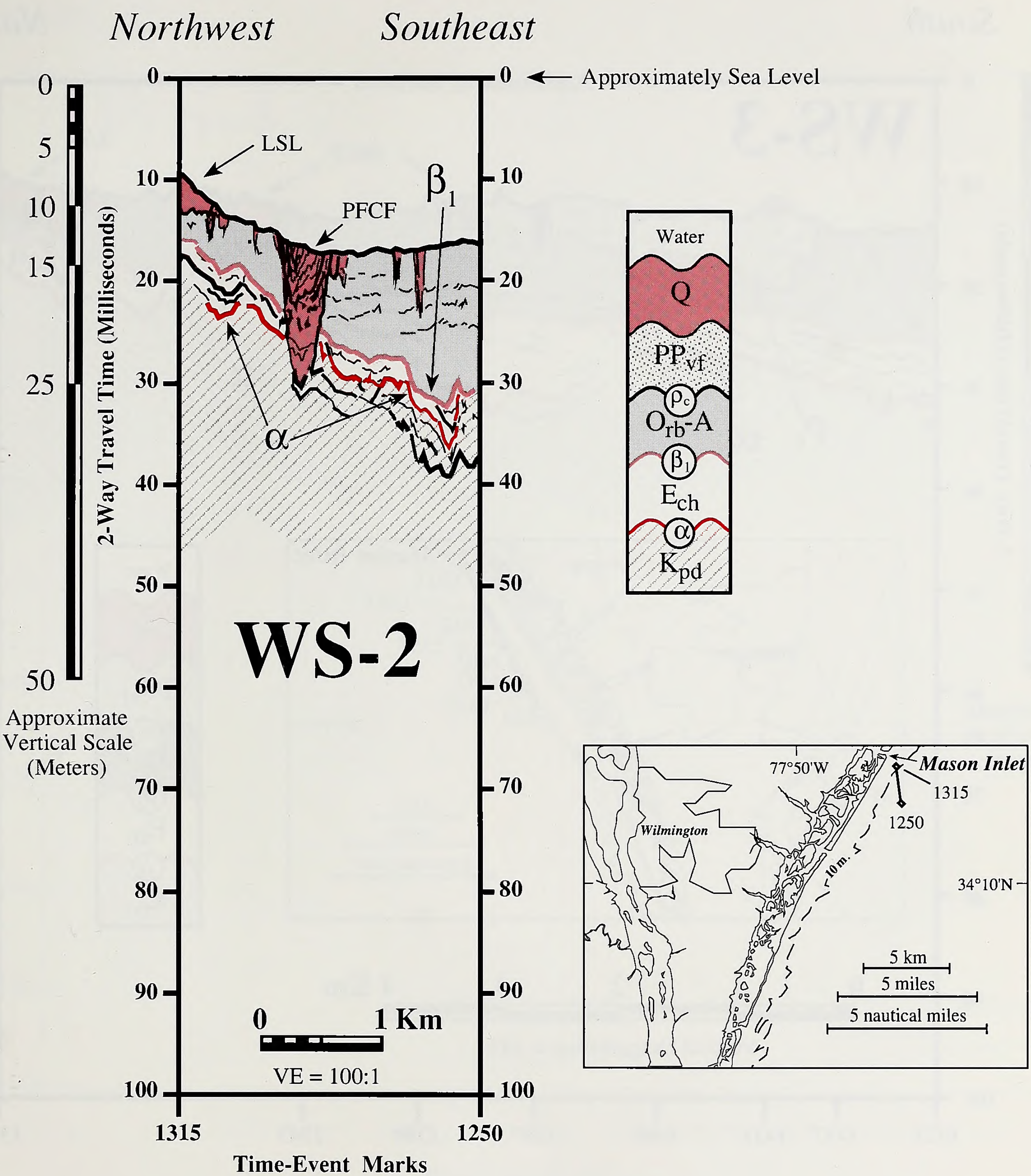


Figure 8. Seismic Section **WS-2**. Time-event marks refer to positions labeled on the map.

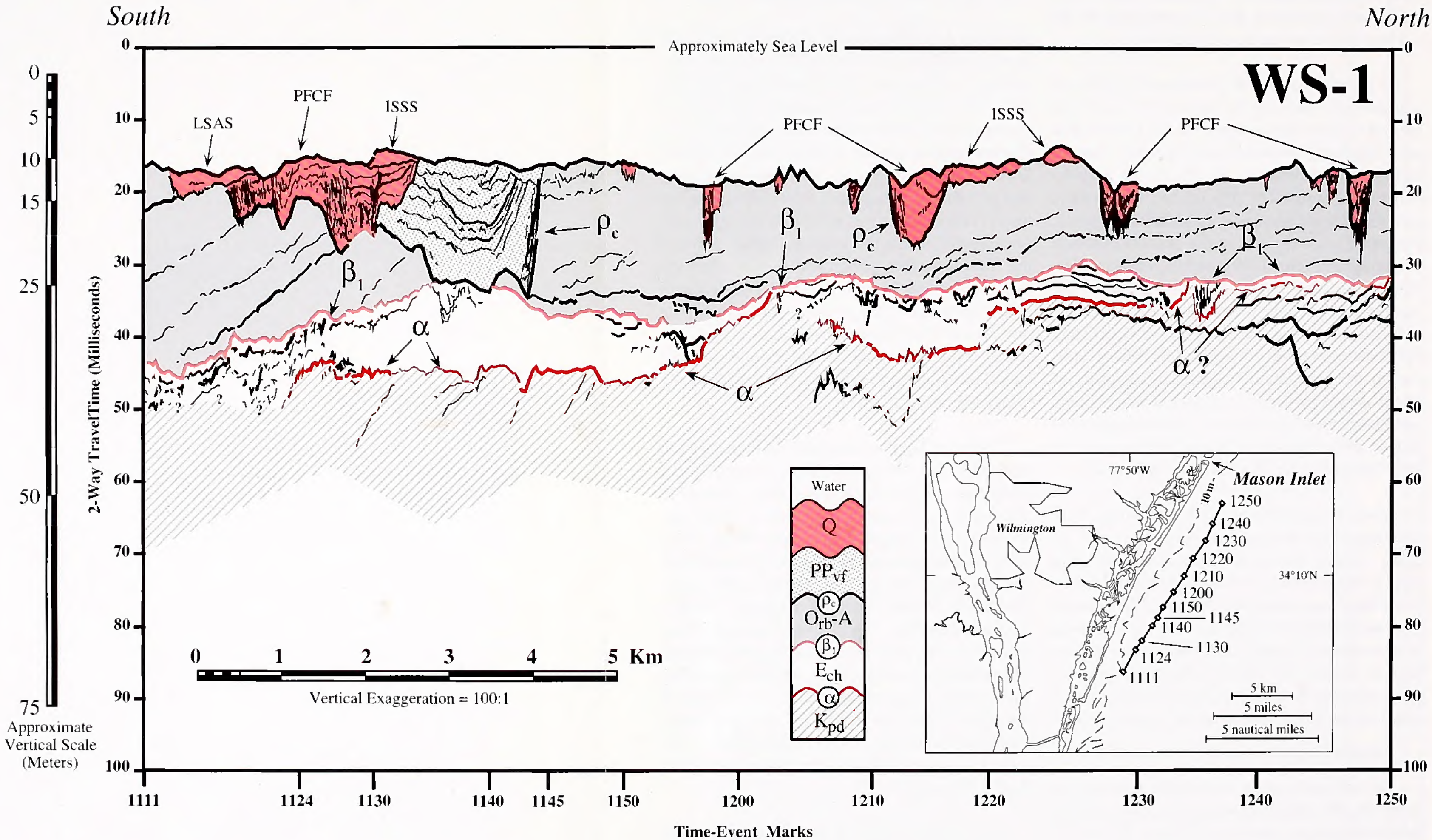


Figure 7. Seismic Section **WS-1**. Time-event marks refer to positions labeled on the map.

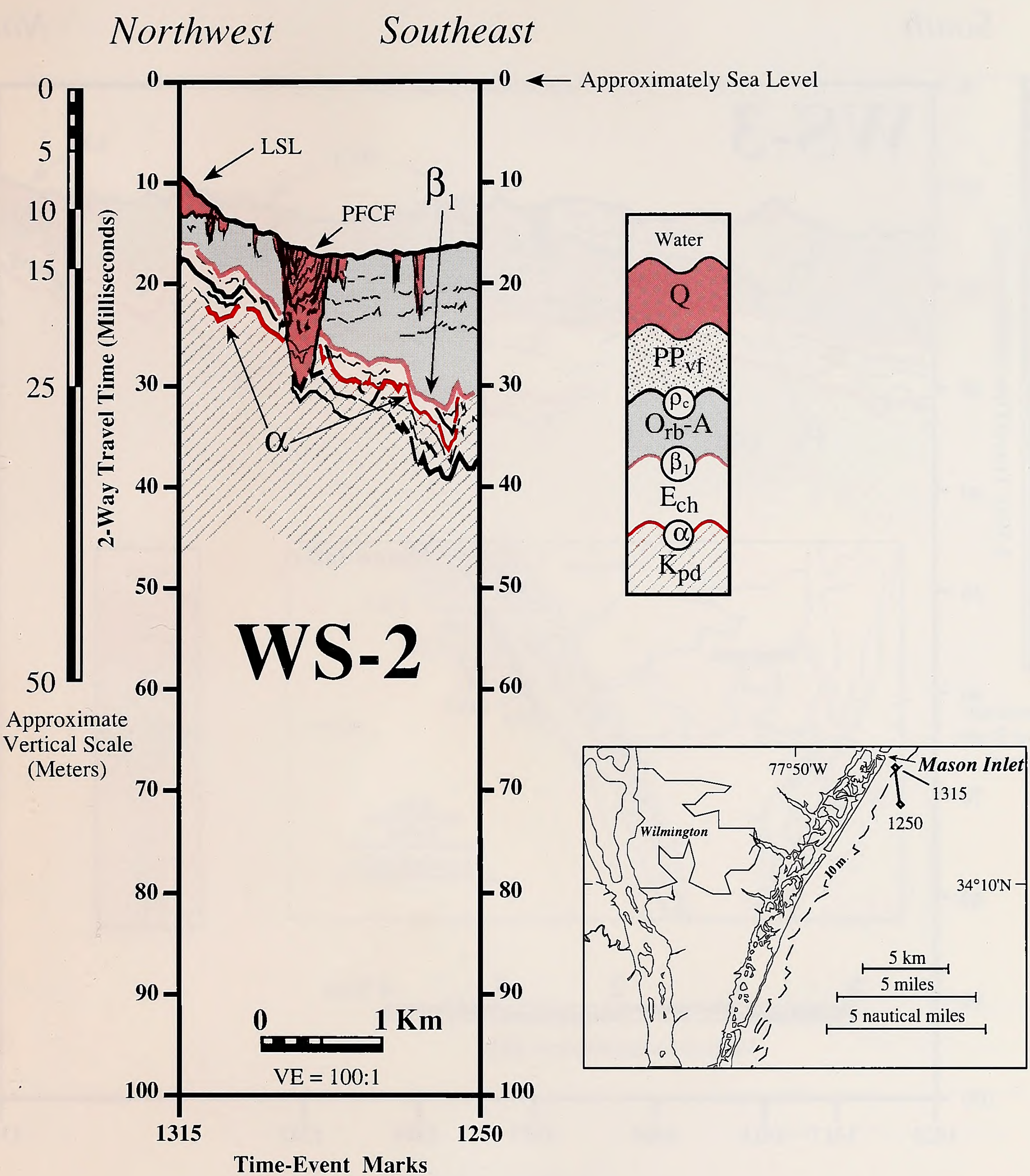


Figure 8. Seismic Section **WS-2**. Time-event marks refer to positions labeled on the map.

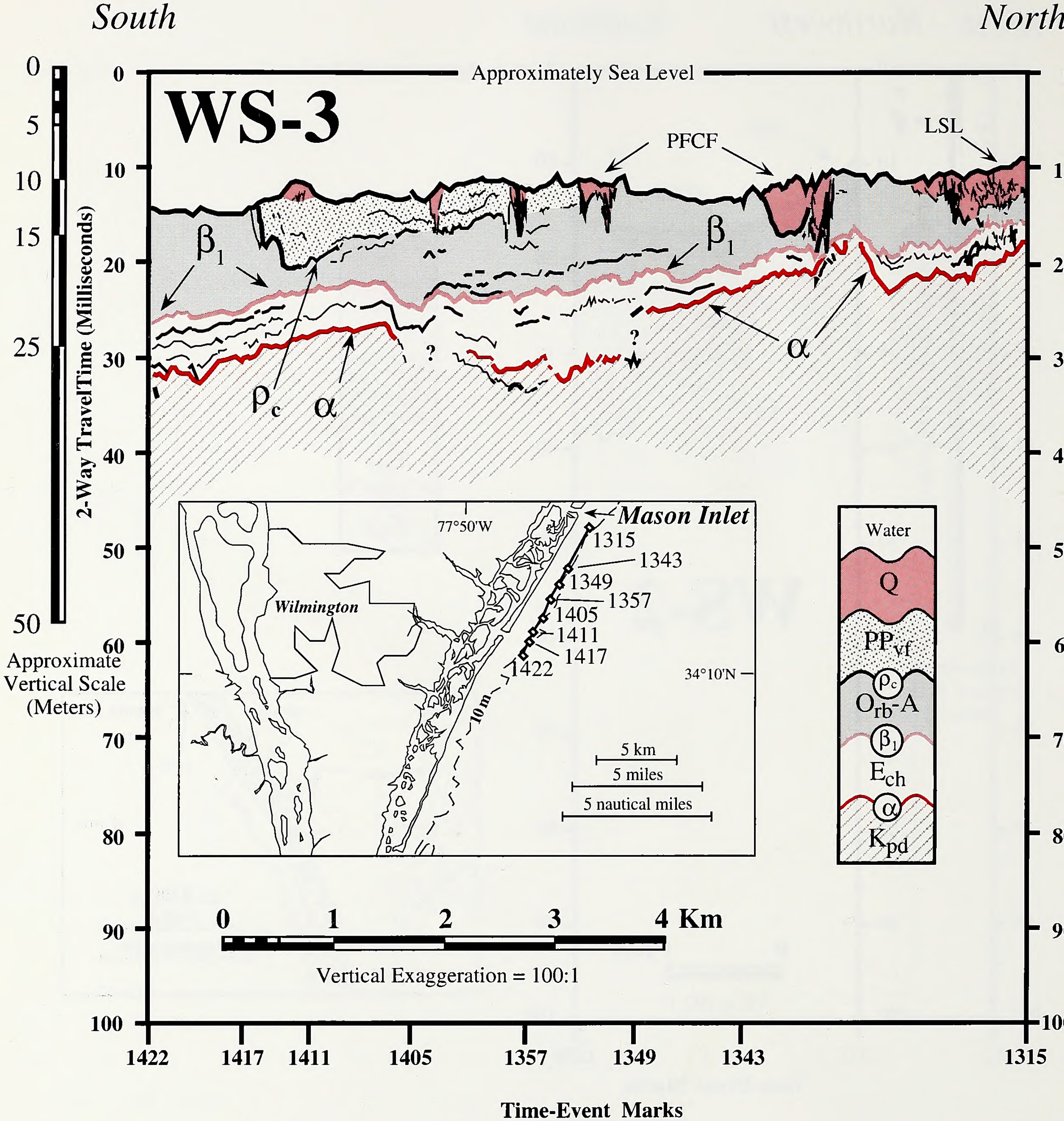


Figure 9. Seismic Section **WS-3**. Time-event marks refer to positions labeled on the map.

Ap
Ve

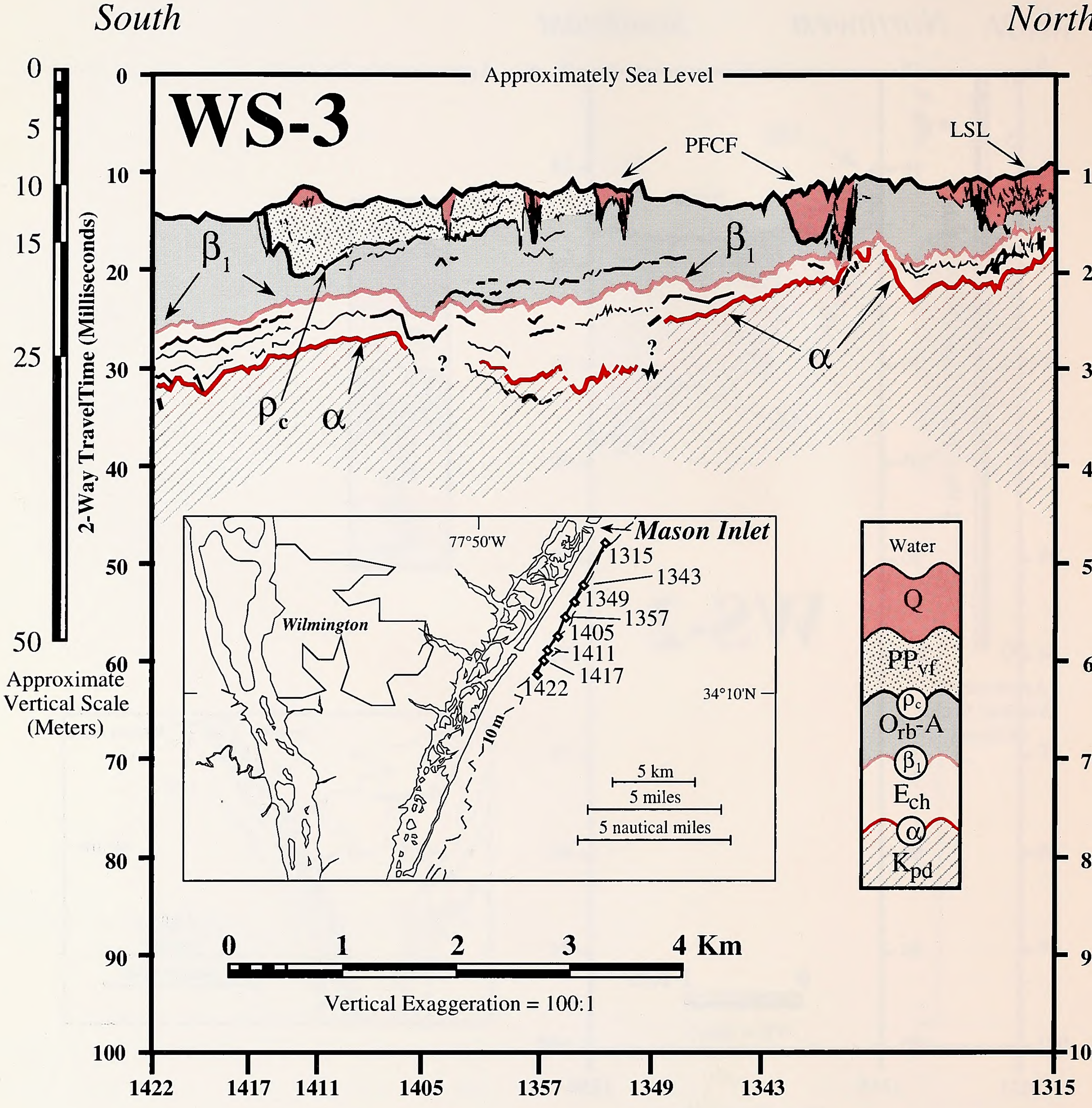


Figure 9. Seismic Section **WS-3**. Time-event marks refer to positions labeled on the map.

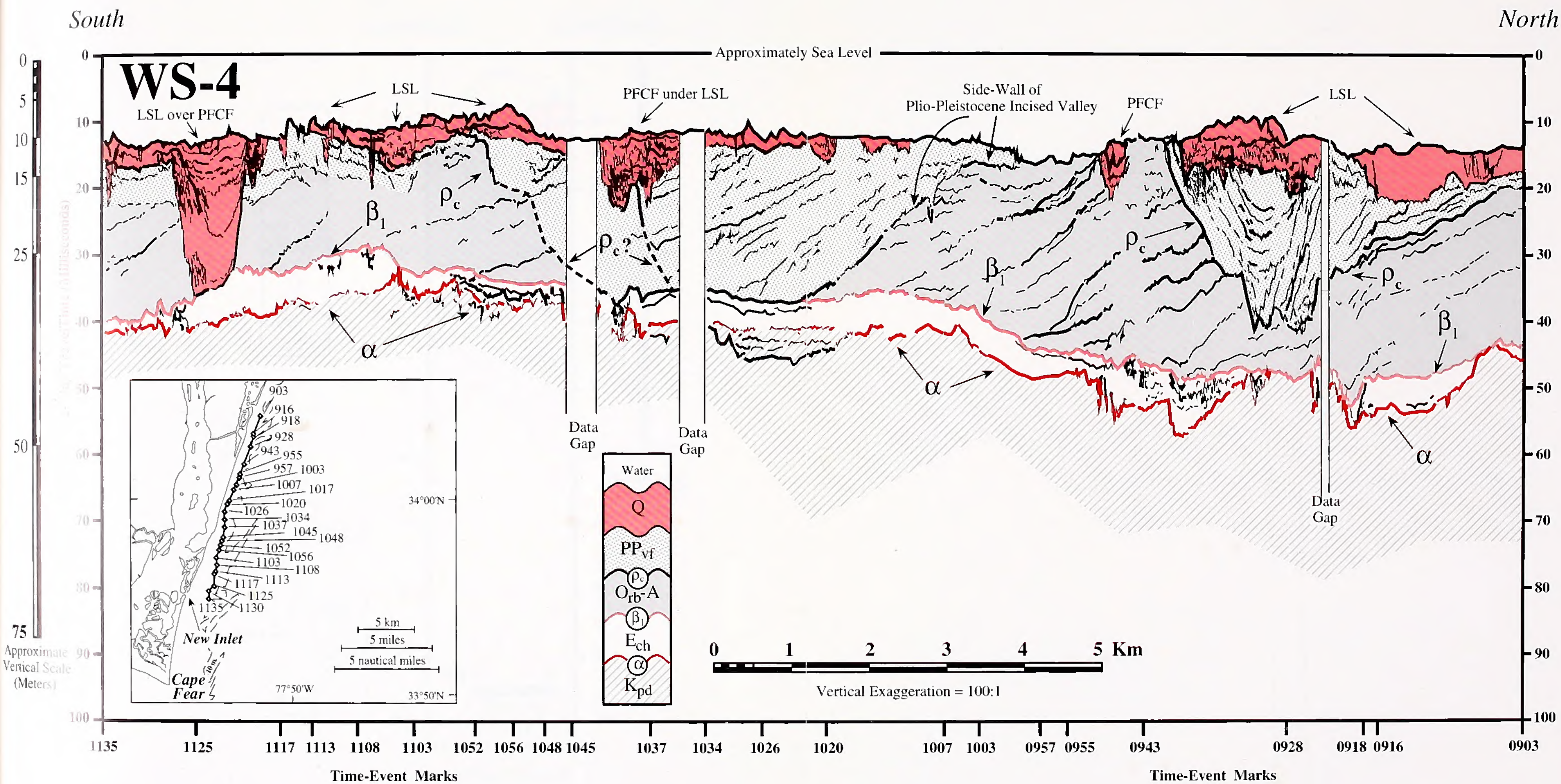


Figure 10. Seismic Section **WS-4**. Time-event marks refer to positions labeled on the map.

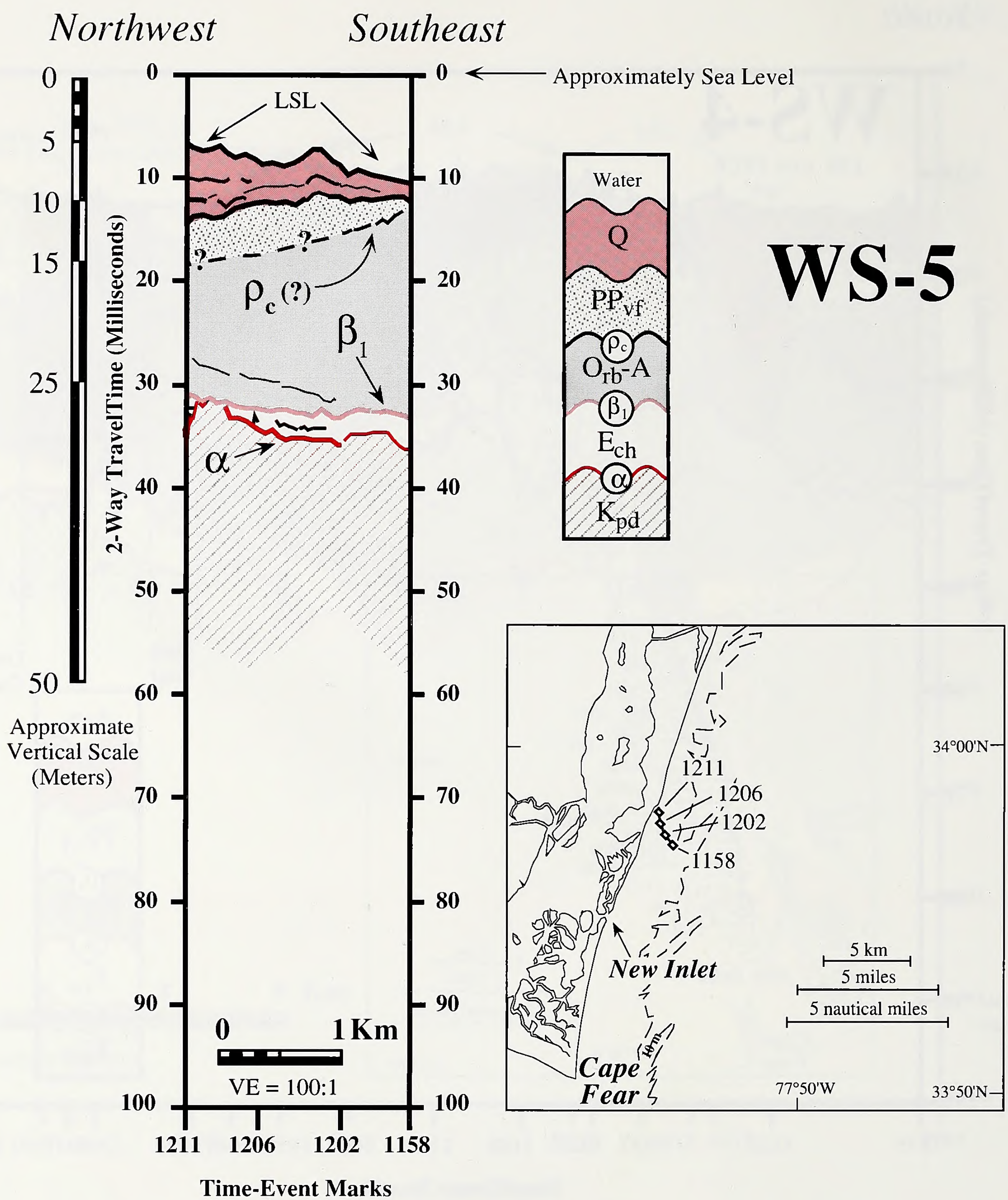


Figure 11. Seismic Section **WS-5**. Time-event marks refer to positions labeled on the map.

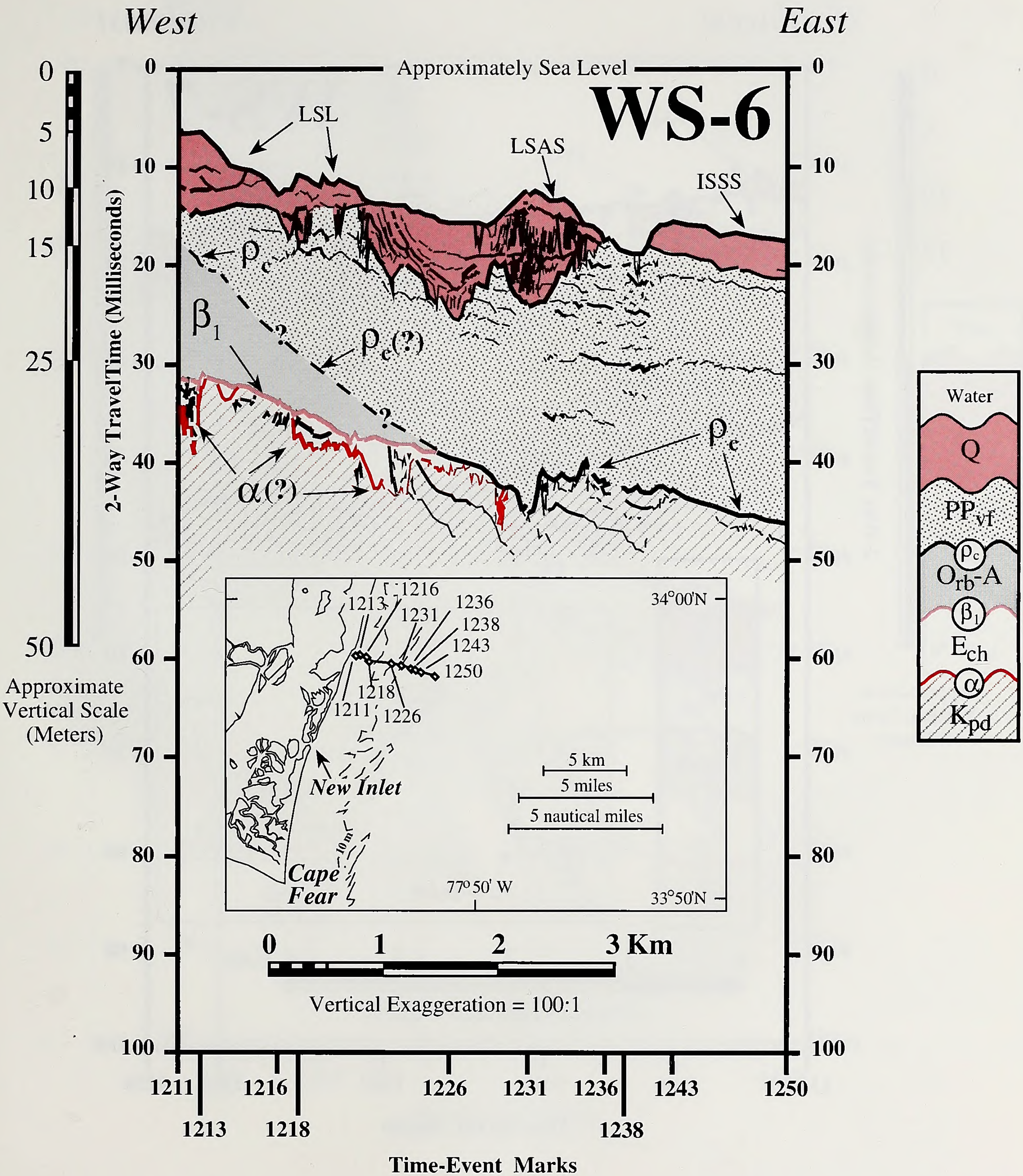


Figure 12. Seismic Section **WS-6**. Time-event marks refer to positions labeled on the map.

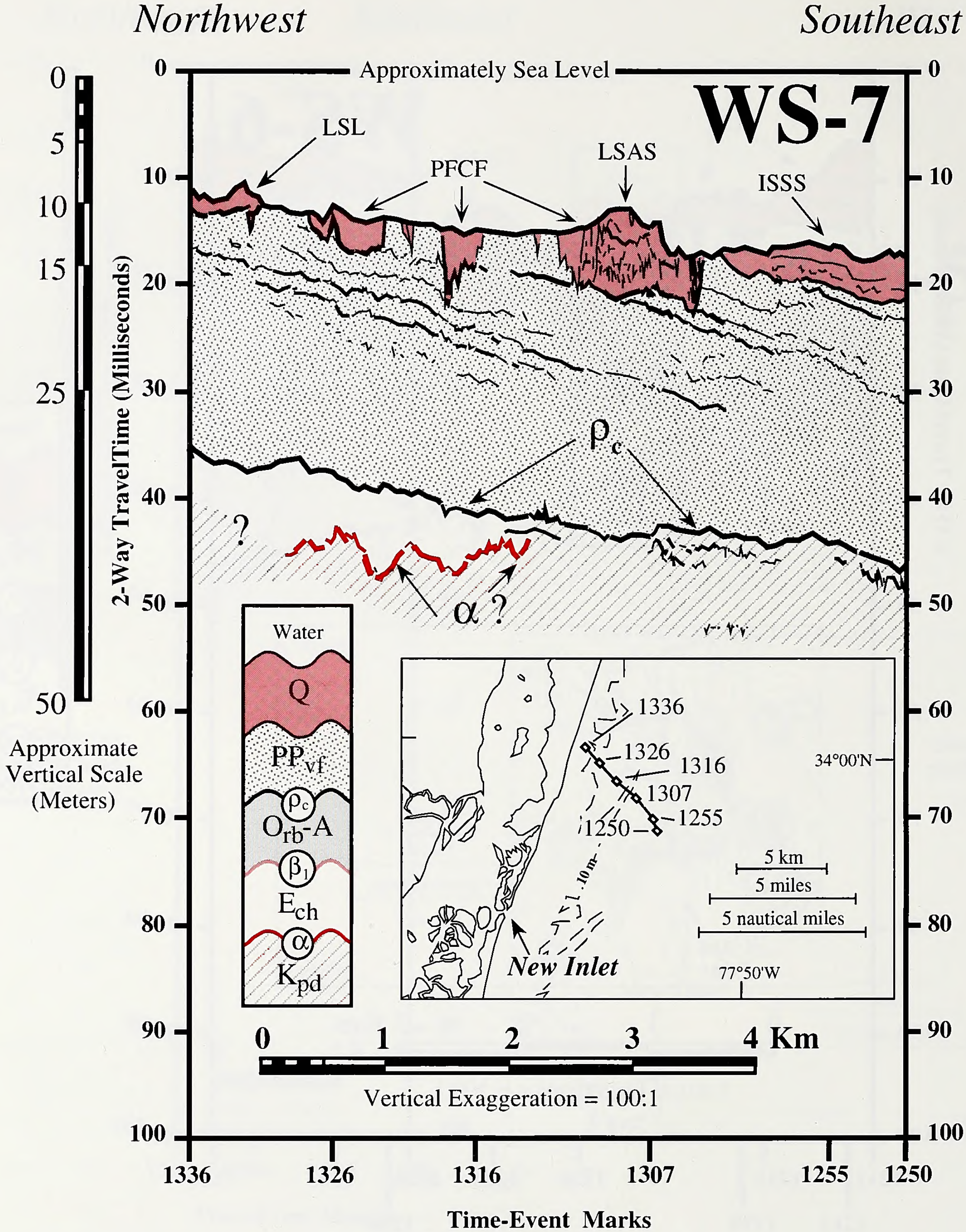


Figure 13. Seismic Section **WS-7**. Time-event marks refer to positions labeled on the map.

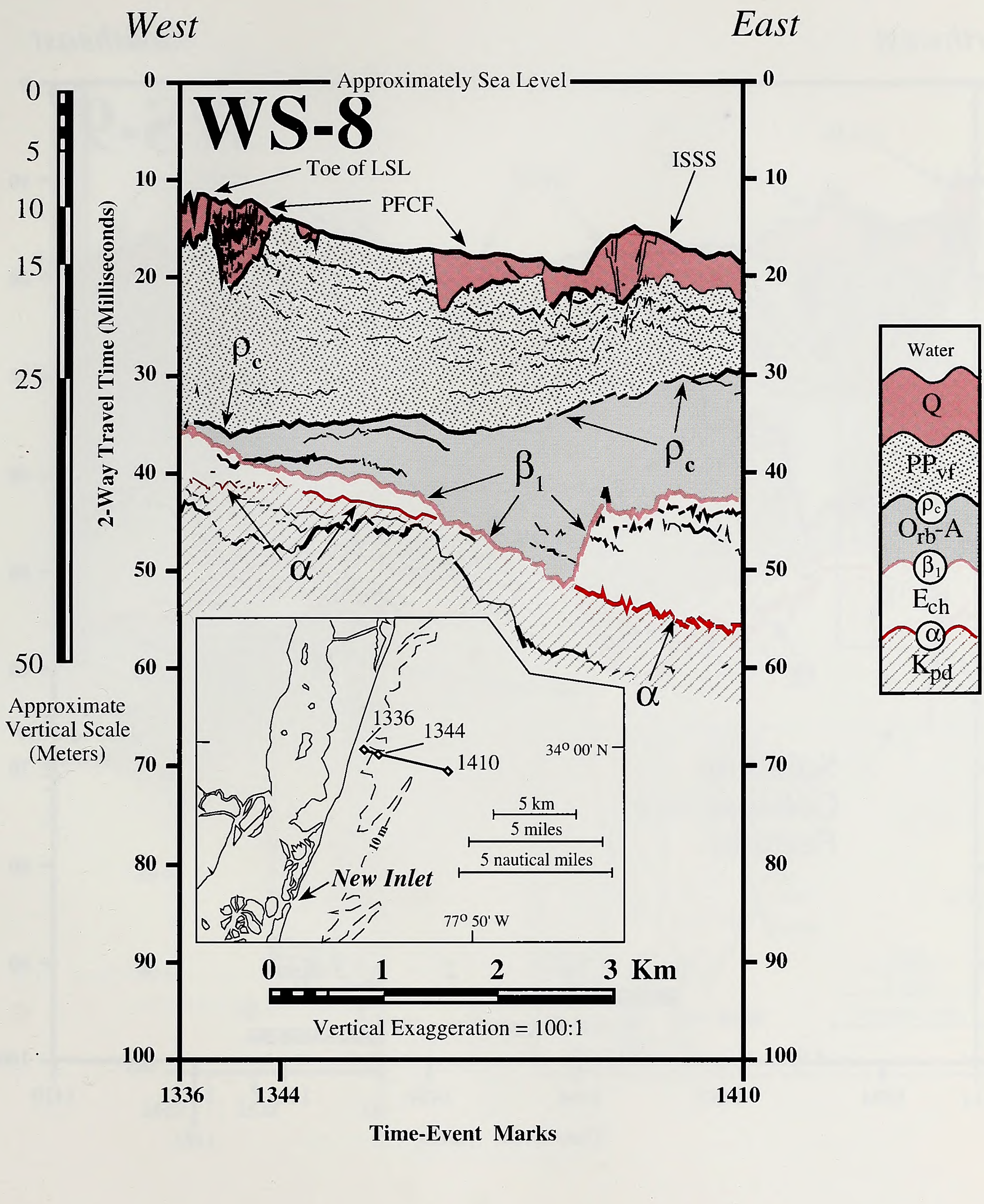
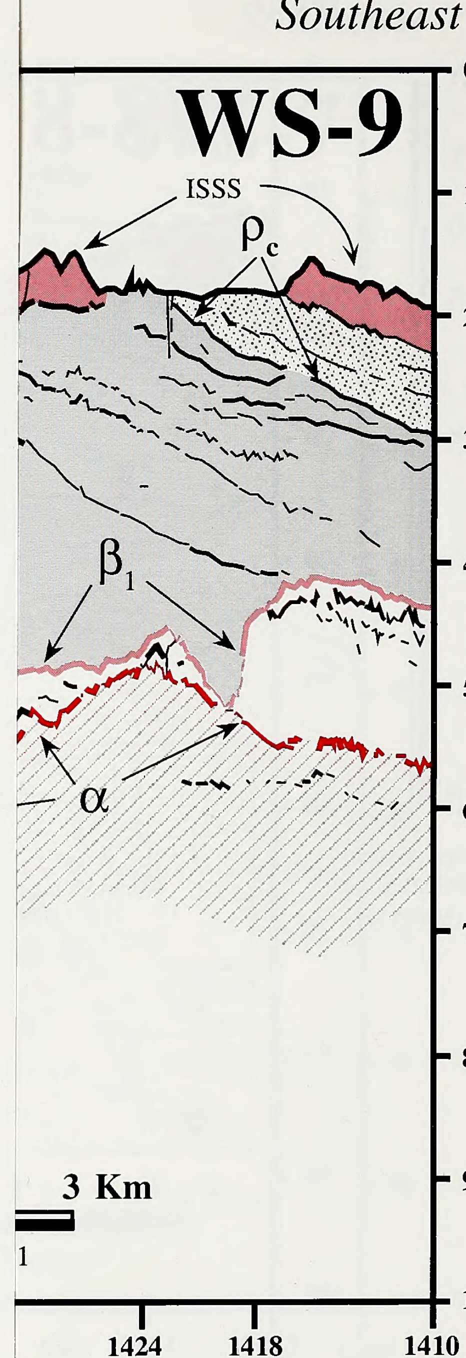


Figure 14. Seismic Section **WS-8**. Time-event marks refer to positions labeled on the map.



efer to positions labeled on the map.

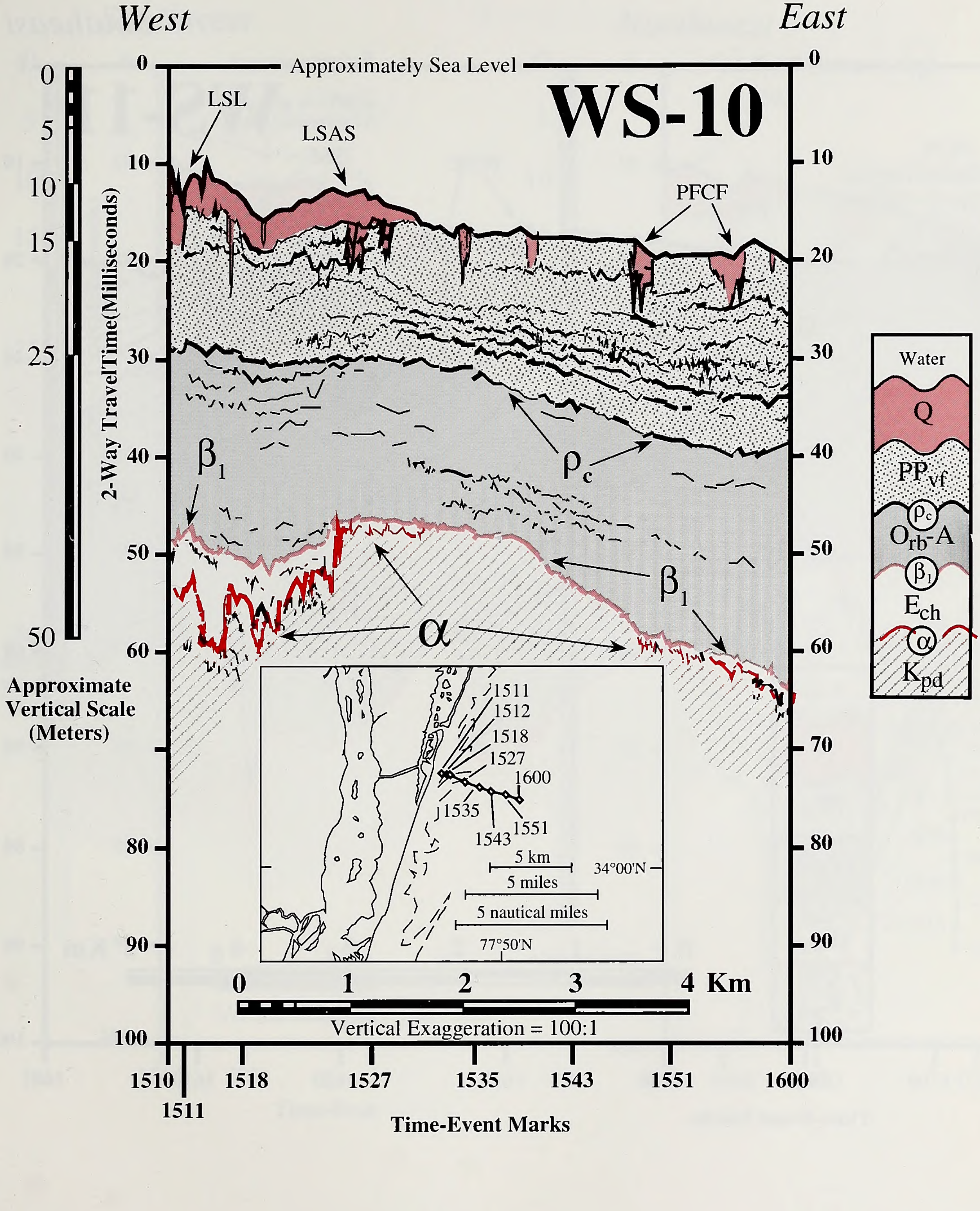
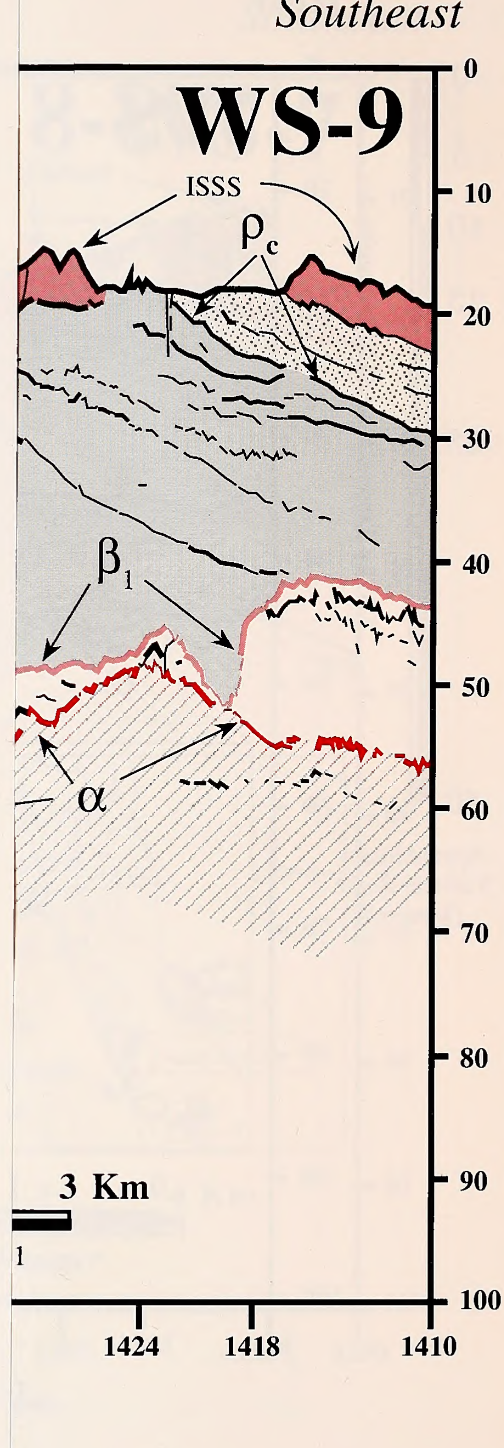


Figure 16. Seismic Section **WS-10**. Time-event marks refer to positions labeled on the map.



efer to positions labeled on the map.

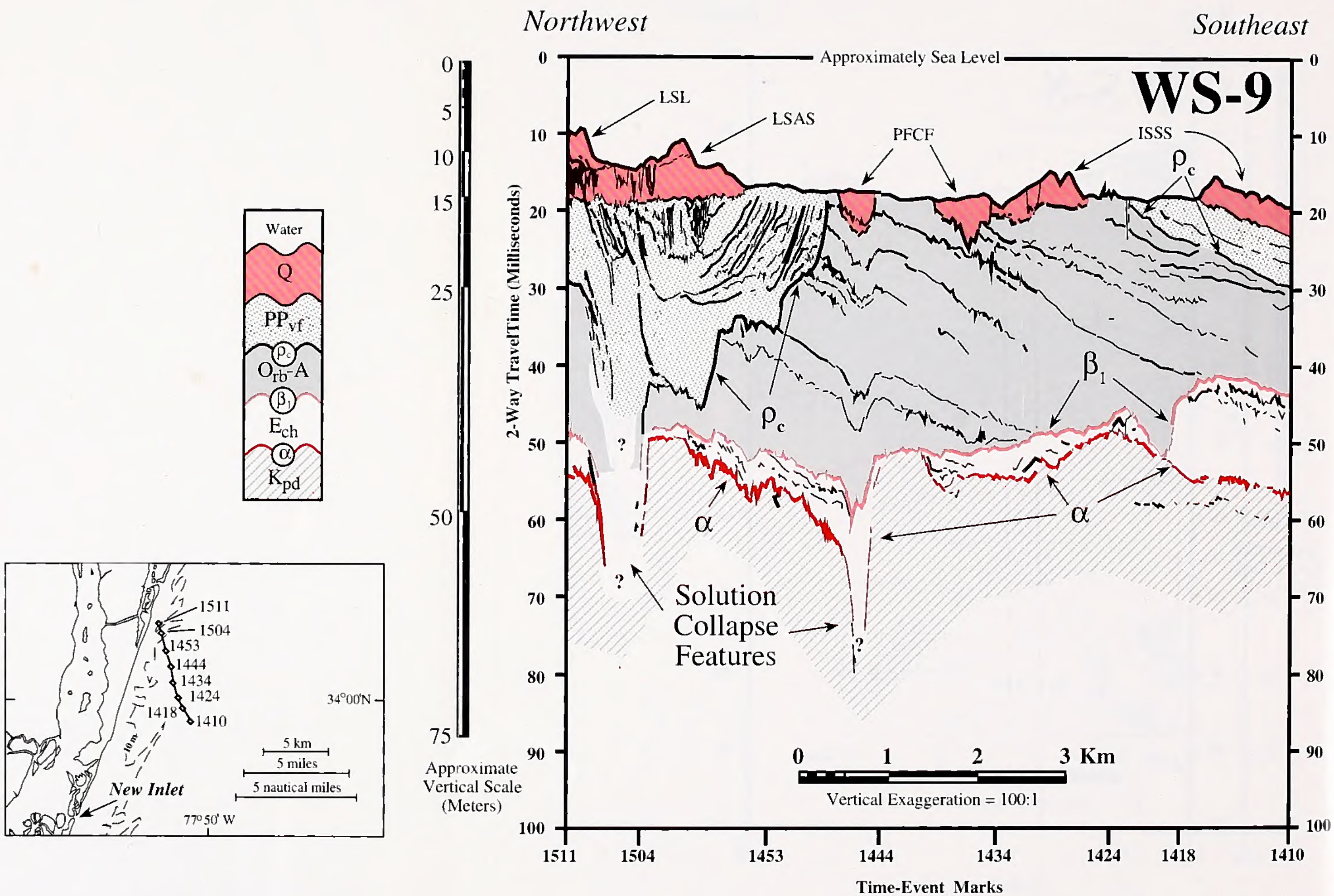


Figure 15. Seismic Section **WS-9**. Time-event marks refer to positions labeled on the map.

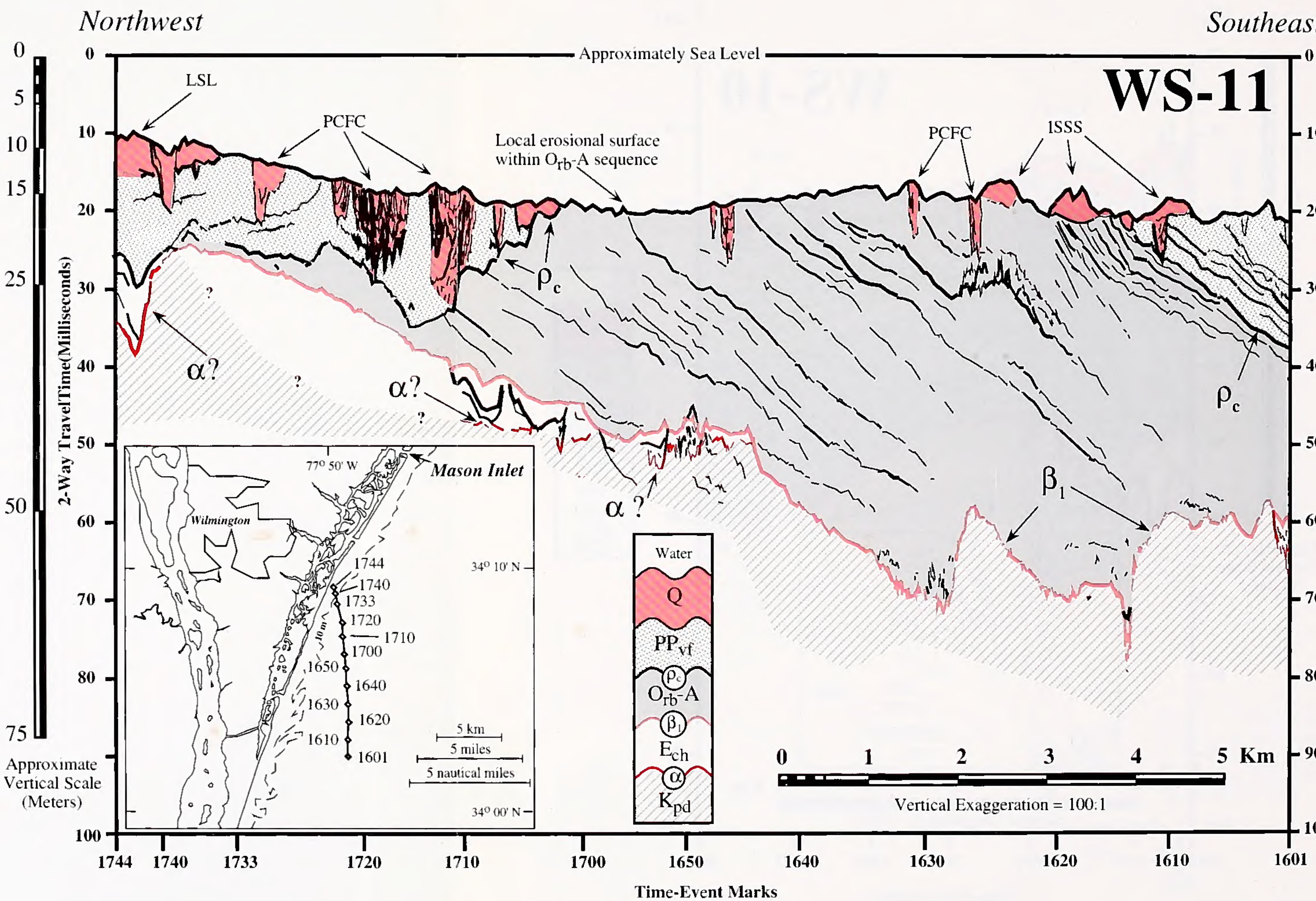


Figure 17. Seismic Section **WS-11**. Time-event marks refer to positions labeled on the map.

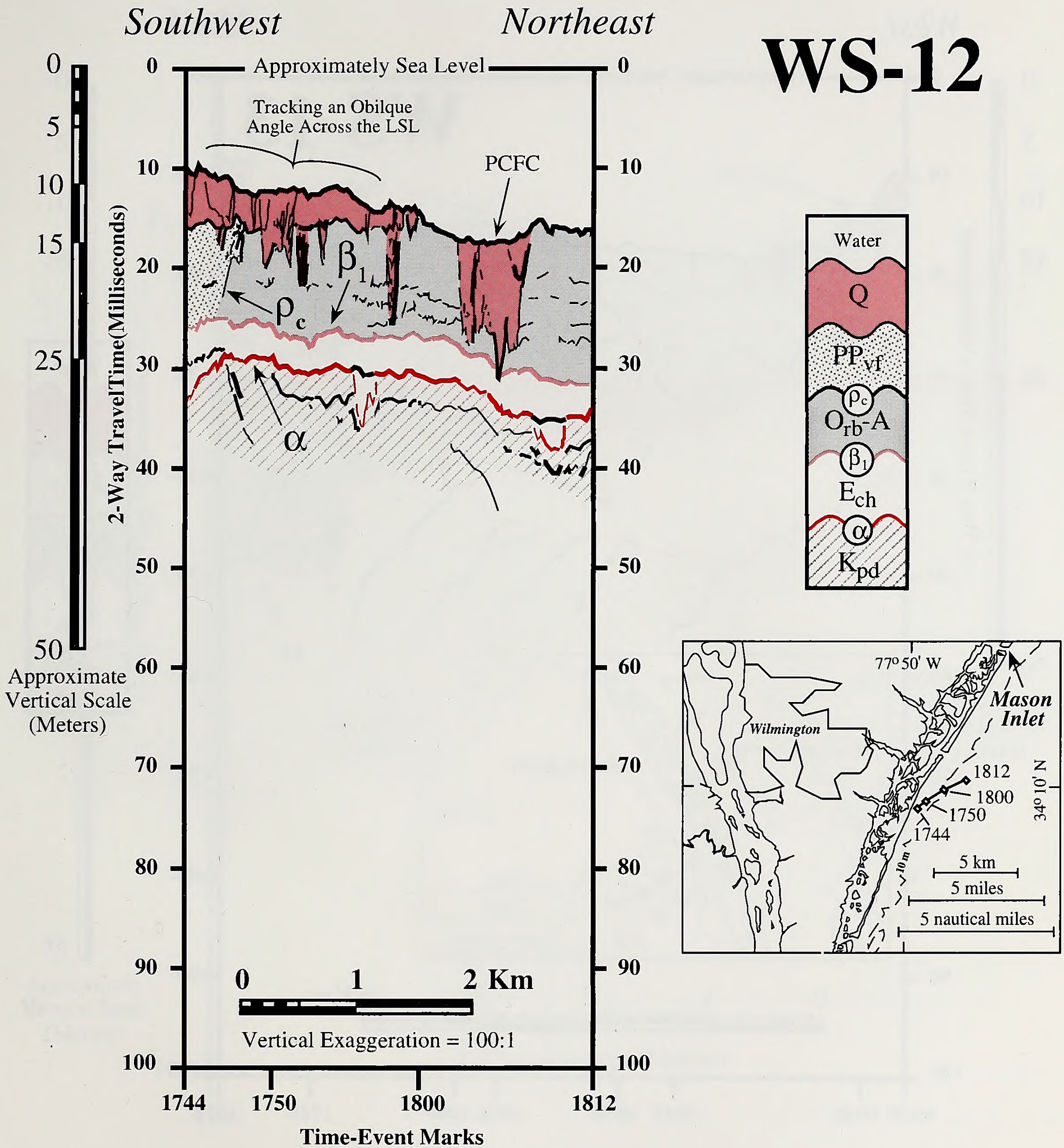


Figure 18. Seismic Section **WS-12**. Time-event marks refer to positions labeled on the map.

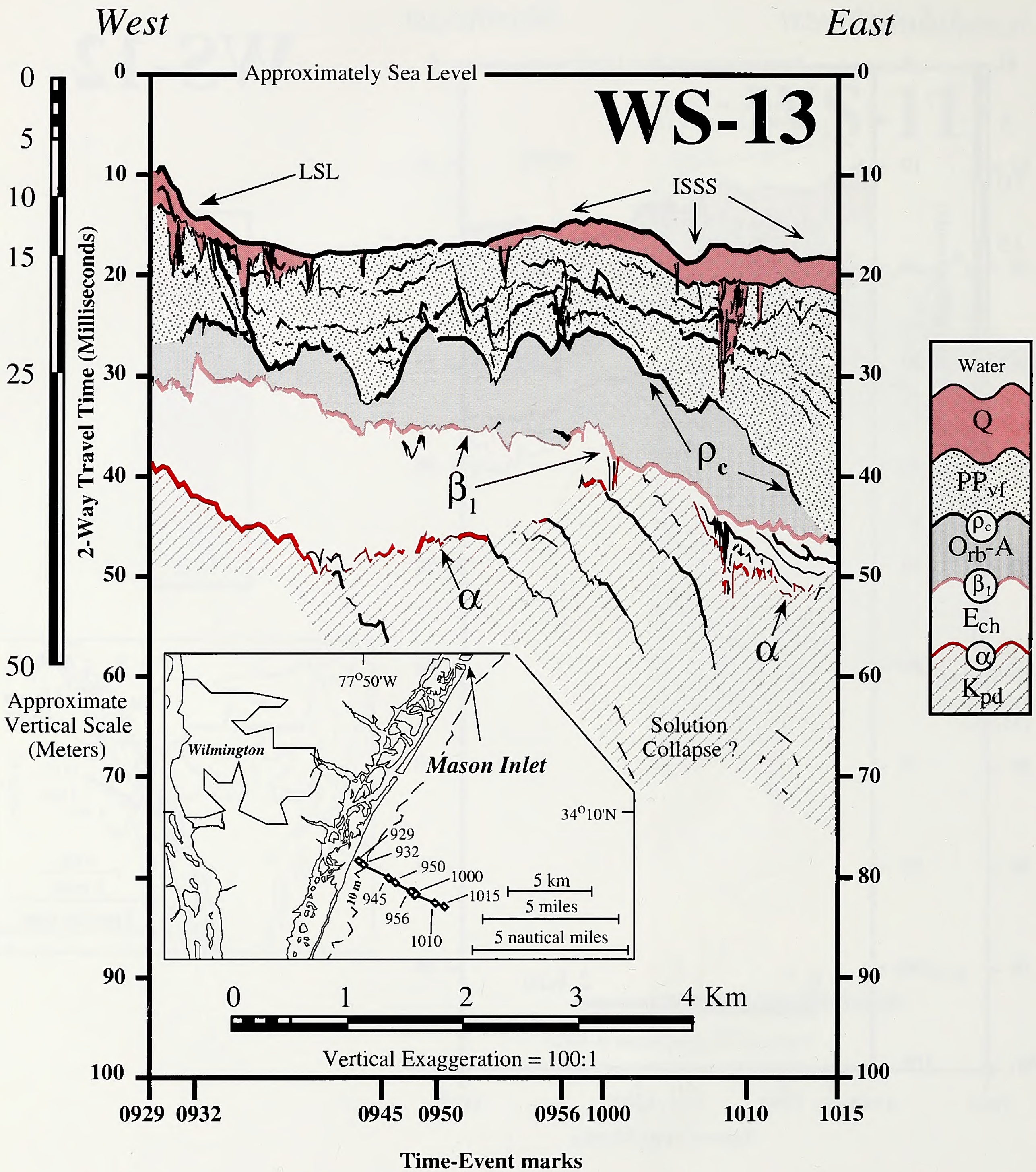


Figure 19. Seismic Section **WS-13**. Time-event marks refer to positions labeled on the map.

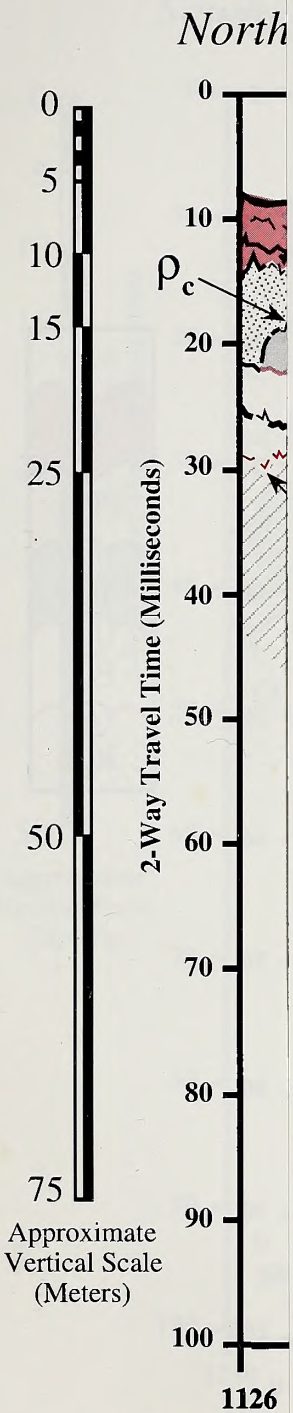


Figure 20. Seismic S

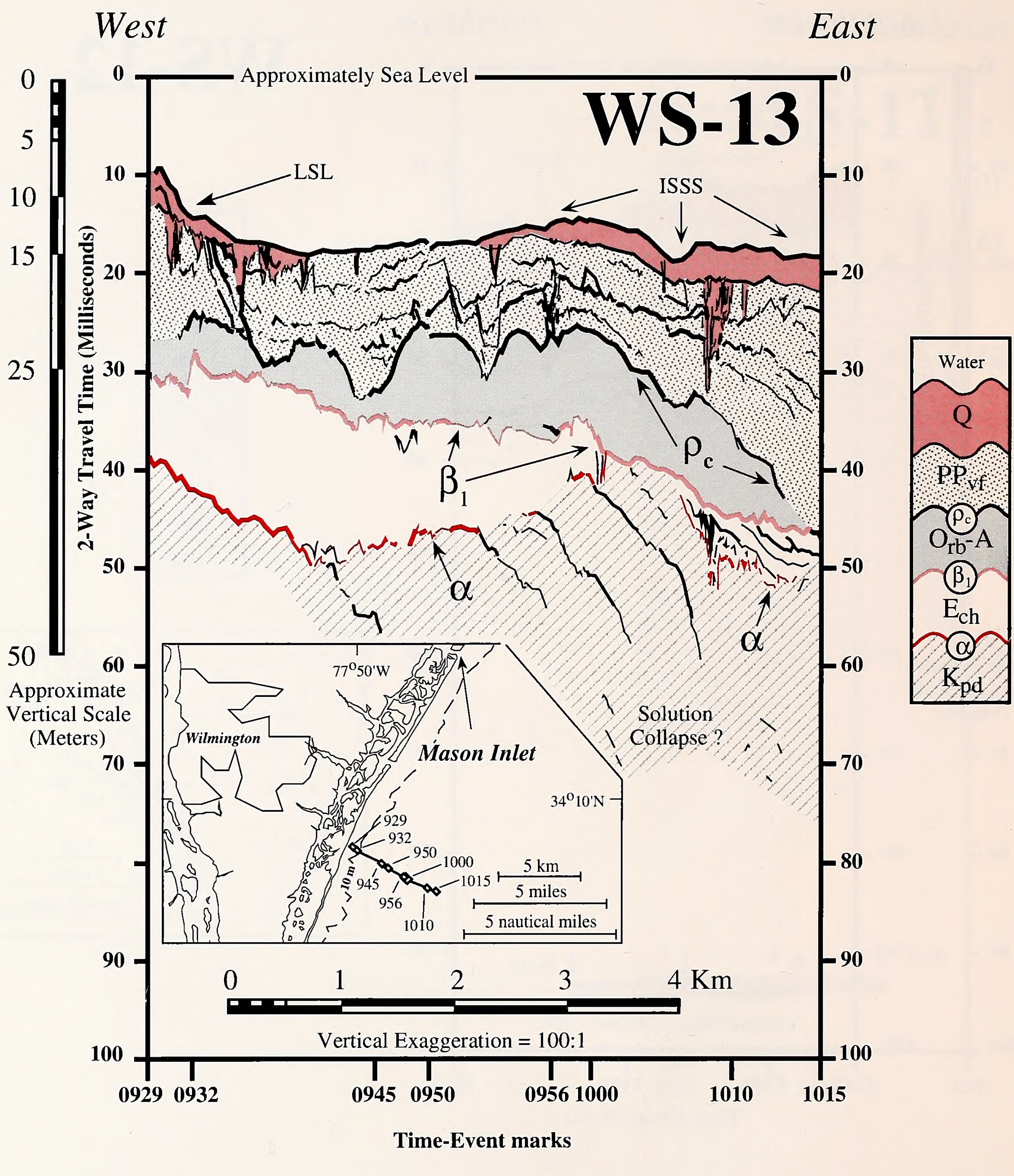


Figure 19. Seismic Section **WS-13**. Time-event marks refer to positions labeled on the map.

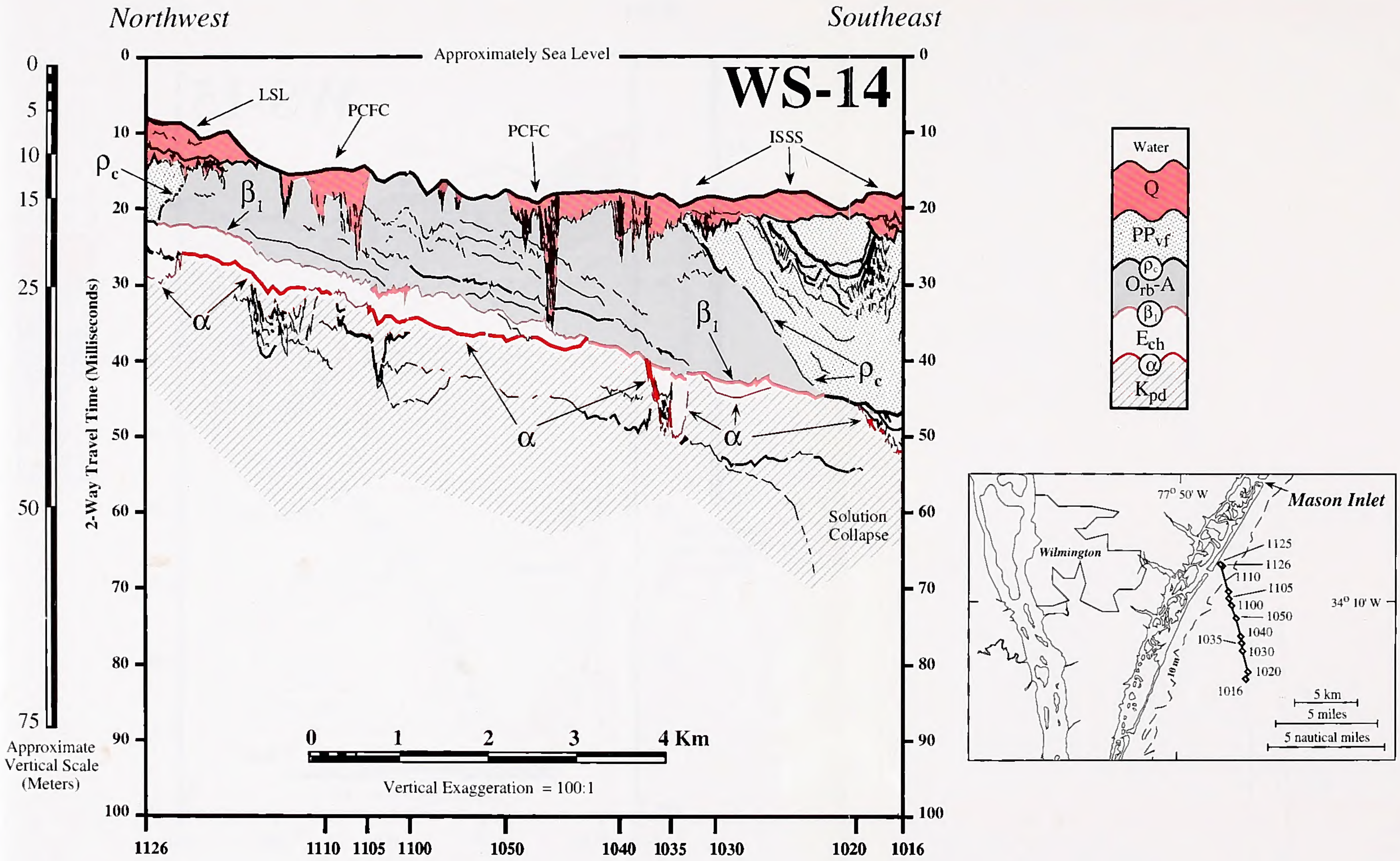


Figure 20. Seismic Section **WS-14**. Time-event marks refer to positions labeled on the map.

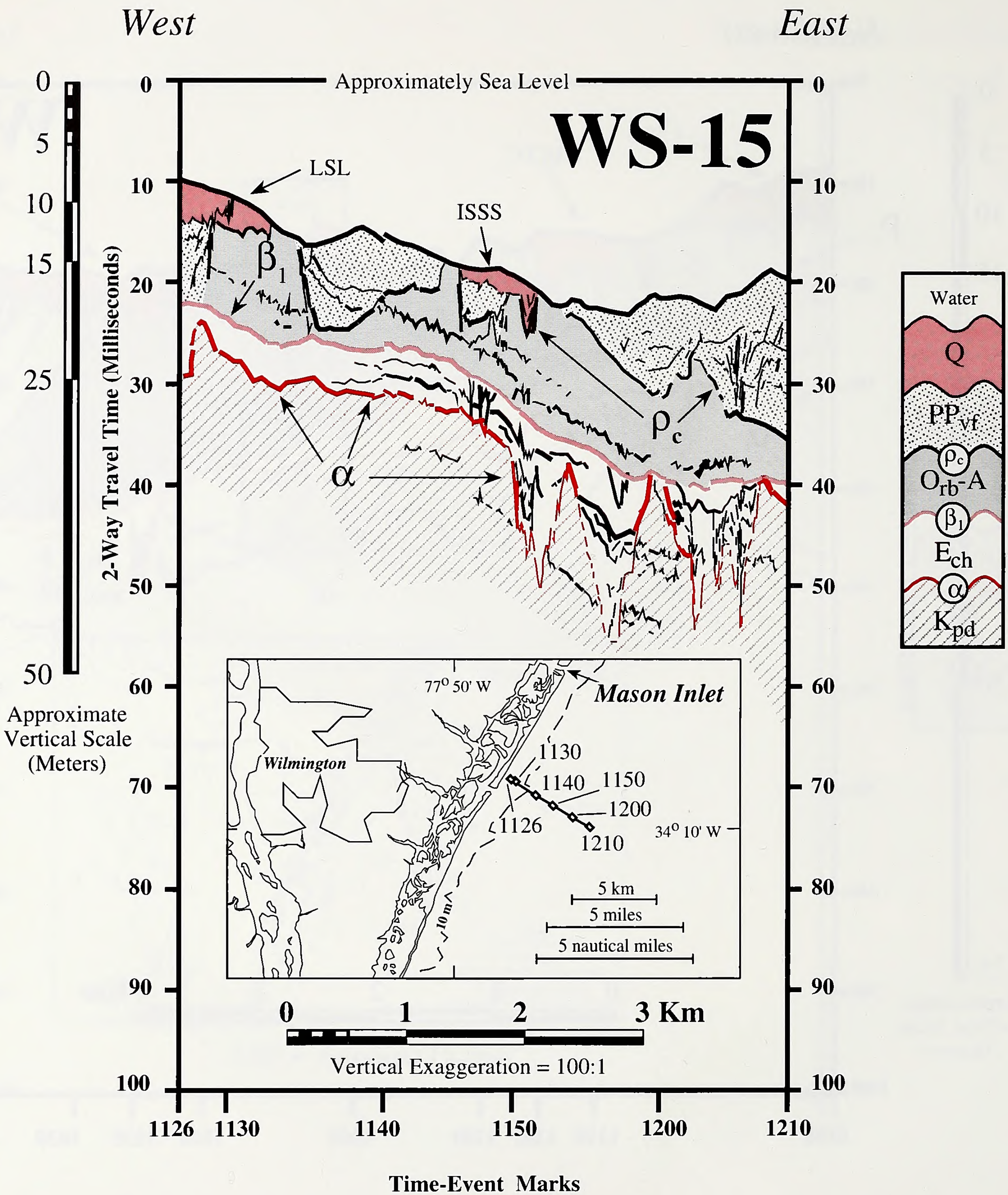


Figure 21. Seismic Section **WS-15**. Time-event marks refer to positions labeled on the map.

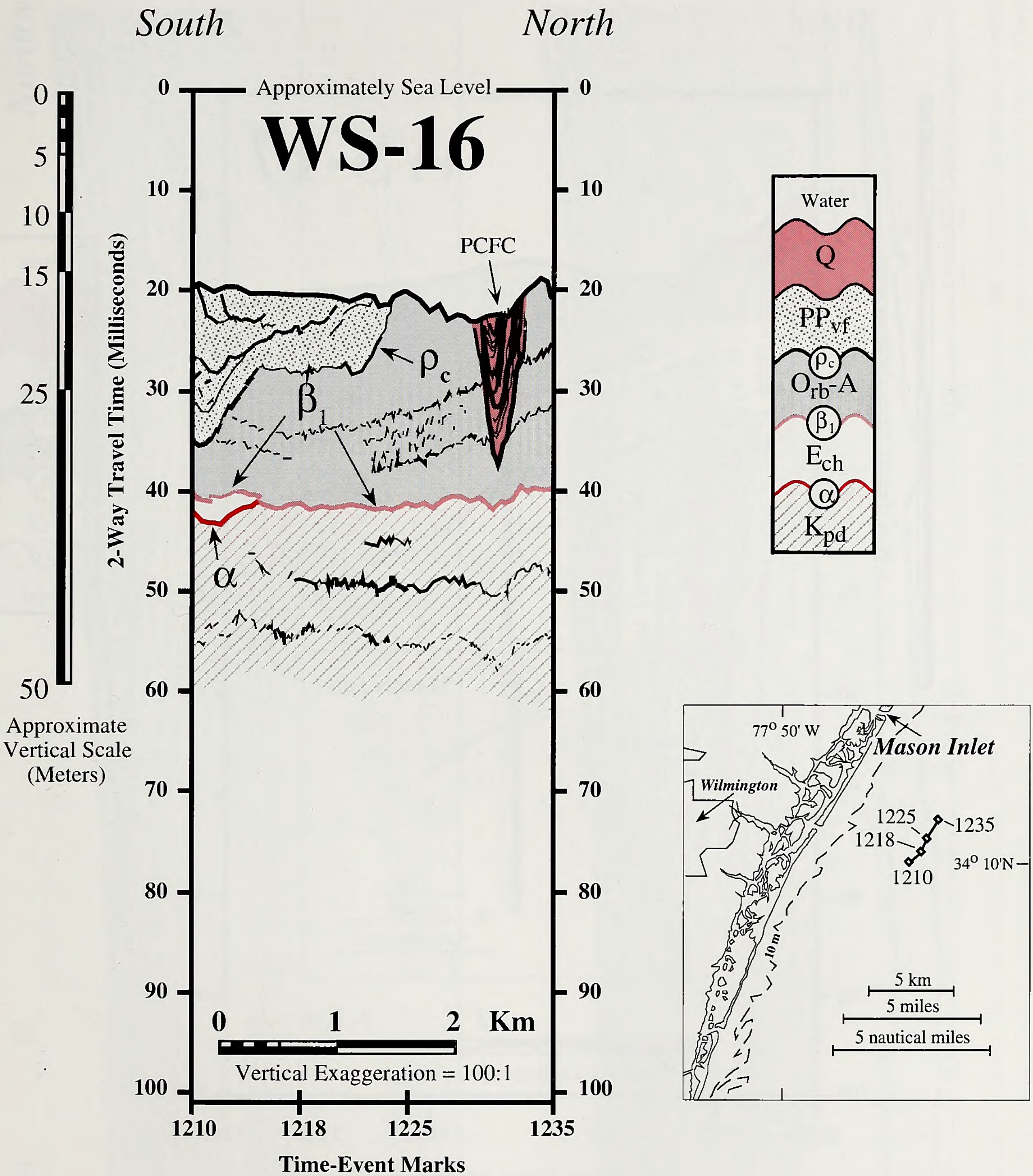


Figure 22. Seismic Section **WS-16**. Time-event marks refer to positions labeled on the map.

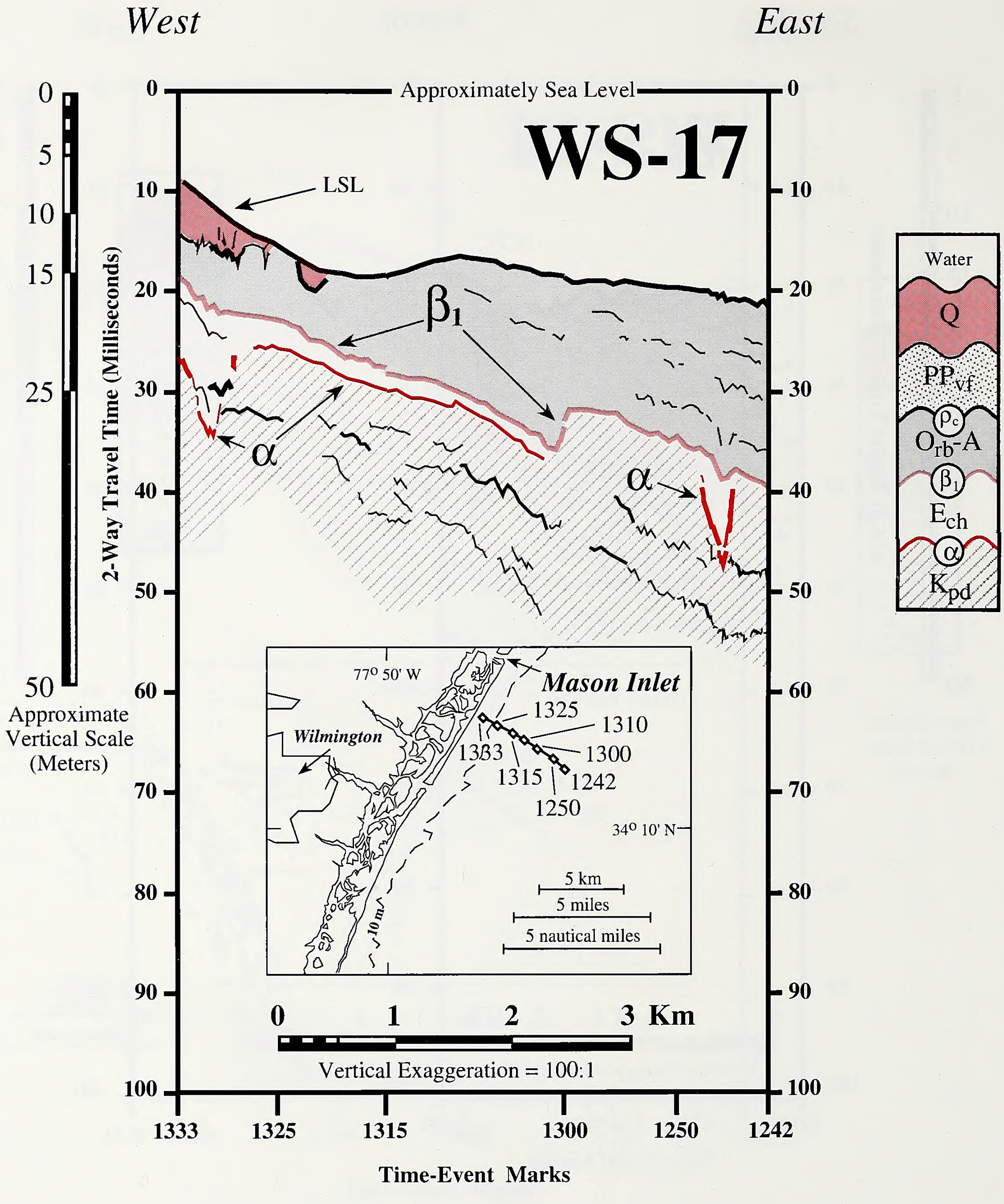


Figure 23. Seismic Section **WS-17**. Time-event marks refer to positions labeled on the map.

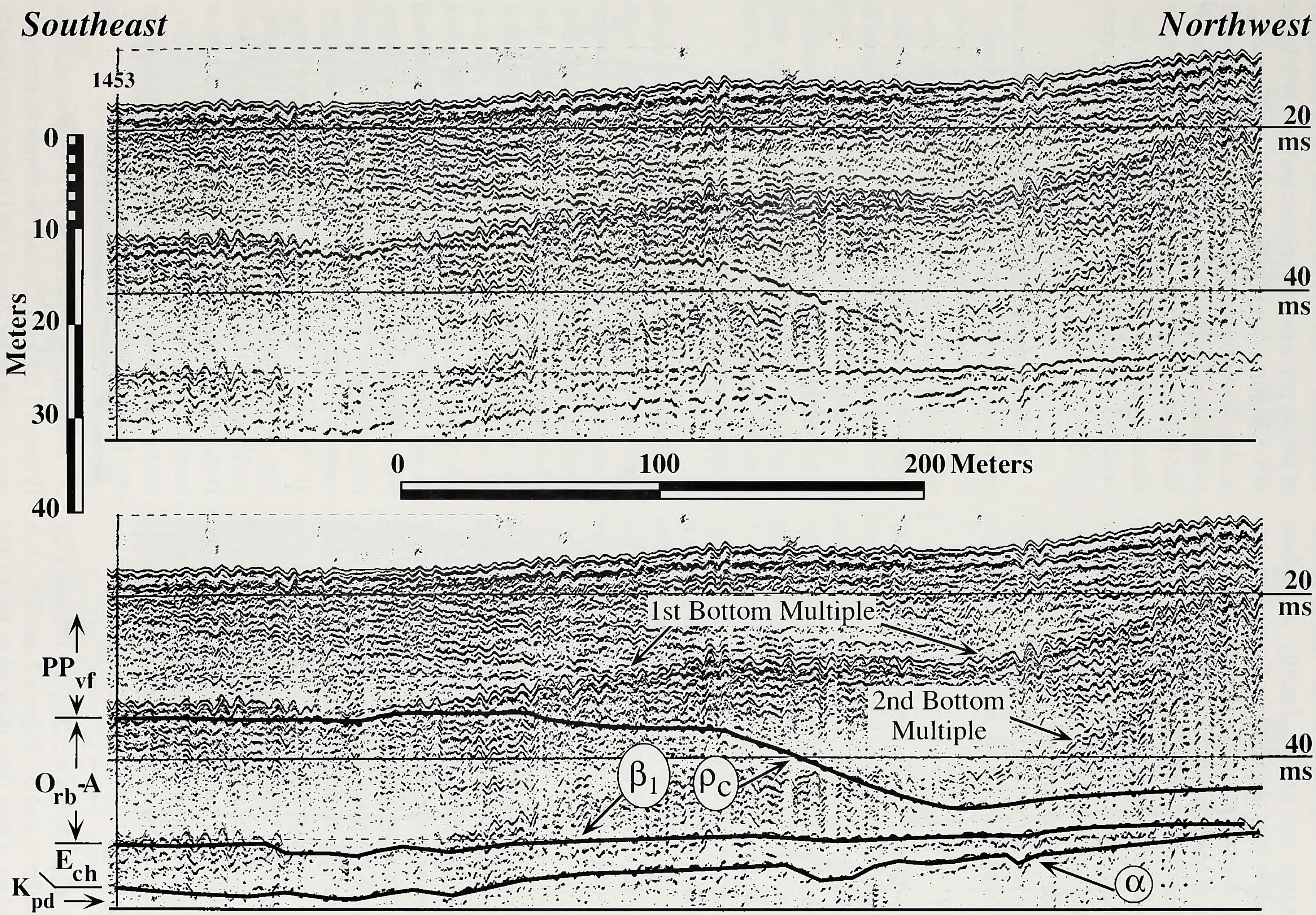


Figure 24. UNIBOOM™ seismic data from seismic section WS-9. Top panel presents the original graphic section; the lower panel delineates the position of unconformities α, β_1, and ρ_c which bound sequences K_{pd}, E_{ch}, O_{rb}-A, and the PP_{vf} lithosome. Quaternary lithosomes are not annotated on the figure. The vertical scale bar is approximate, and based on a time-to-depth conversion of 1700 meters/second.

of glauconite, phosphorite, oyster shells, opaque mineral grains, and pyrite. Locally, at onshore sites, the upper part of the Upper Cretaceous section includes a molluscan biomicrudite named the Rocky Point Member of the Peedee Formation (Wheeler and Curran, 1974; Harris, 1975). Several solution collapse features observed on the seismic sections seem to be rooted in the K_{pd} sequence (for example, see line WS-9 in Figure 15). This implies that the Late Cretaceous section underlying the survey area is a carbonate-rich aquifer vulnerable to subterranean dissolution and subsequent collapse.

Unconformity α The lowermost unconformity surface identified is a very high-amplitude, continuous, seismic reflector. It exhibits significant topographic relief (3 to 5 meters) in many of the seismic sections (Figure 25). It also appears as an angular unconformity in seismic section WS-1 (between time-event marks 1124 and 1150 in Figure 7). Channels are cut into this surface as well (Figures 25, 26, and 27). The channeling suggests surface α was created by subaerial exposure followed by truncation via a subsequent transgressive surface.

Seismic sections WS-1 (Figure 7) and WS-4 (Figure 10) show the α surface is locally truncated by reflector/unconformity β_1. This is particularly common in the southern part of the survey area. The truncation is well illustrated in Figures 28 and 29. Although the α unconformity is a continuous surface, it merges with the younger unconformity β_1 where subsequent erosion has removed the intervening strata. Moreover, common mergers between surfaces β_1 and α in the northern part of the survey area has caused a highly discontinuous subcrop distribution of the reflector and has prevented tracing the α surface with a high level of confidence in this area.

Sequence E_{ch} Sequence E_{ch} is bounded by unconformities α and β_1 (Figures 5 and 24). It is represented by a thin (less than 10 m thick) and discontinuous section throughout the northern part of the survey area (see seismic sections WS-1 and WS-3; Figures 7 and 9 respectively). Sequence E_{ch} is also discontinuous through the south and east portions the study area due to excavation by the β_1 unconformity surface. Figures 28 and 29 illustrate these E_{ch} pinchout patterns (also see seismic sections WS-4 and WS-9 in Figures 10 and 15, respectively).

In the northern portion of the survey area, the seismic facies of sequence E_{ch} is characterized by a series of high-frequency, moderate-amplitude reflectors (Figure 30). In the southern map area, however, the predominant seismic facies is reflection-free. Also, sequence E_{ch} is limited to channels or low areas in the α unconformity surface. This relationship has produced much of the discontinuous, pinch-and-swell subcrop pattern which characterizes sequence E_{ch} in the southern part of the mapped area (Figure 29).

Sequence E_{ch} is not exposed on the continental shelf in the map area (Figure 4), but it has been traced westward in the subsurface and was found to crop out on the inner and middle shelf of Long Bay where it forms a narrow, north-south-trending linear belt approximately 5 to 8 km wide subparallel to Frying Pan Shoals (Snyder, 1982). It was interpreted as chronostratigraphically equivalent to the middle Eocene Castle Hayne Formation based on correlations to mapped onshore stratigraphies (Snyder, 1982) and analyses of vibracore samples from the offshore outcrop belt (Meisburger, 1979; 1981). Onshore, the Castle Hayne Formation is widespread in both outcrop and subcrop, particularly throughout Brunswick and New Hanover Counties. These onshore sections have been described in detail by Ward and others (1978), Baum and others (1978), Jones (1983), and Zullo and Harris (1987), among many others.

Correlations between the WS-seismic sections (Figures 7 through 23) and the borehole stratigraphy presented by Zarra (1991) have conclusively

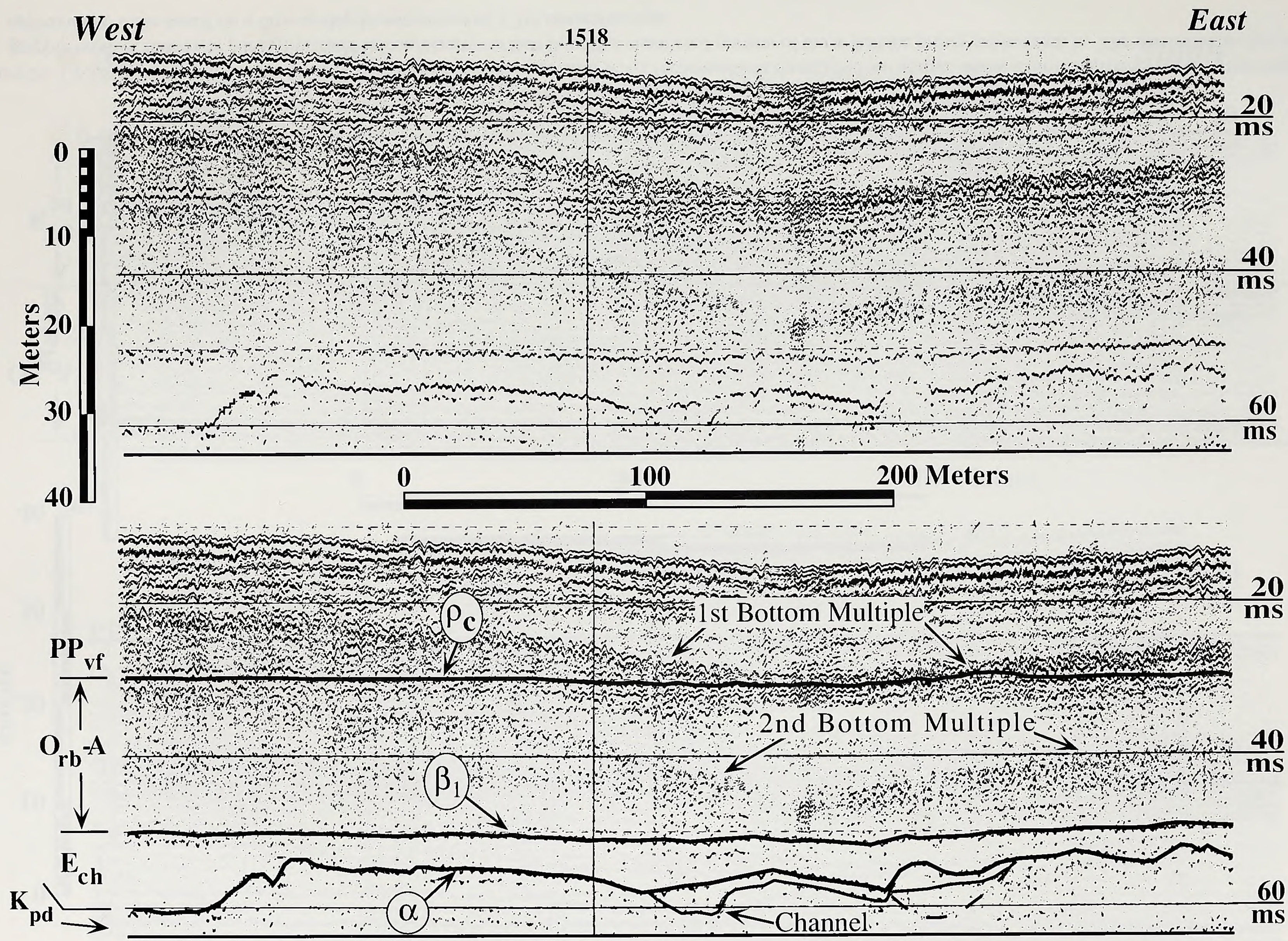


Figure 25. UNIBOOM™ seismic data from seismic section WS-10. Top panel presents the original graphic section; the lower panel depicts the positions of unconformities α, β_1, and ρ_c. Note the channel feature associated with the a surface. Quaternary lithosomes are not annotated on the figure. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/second.

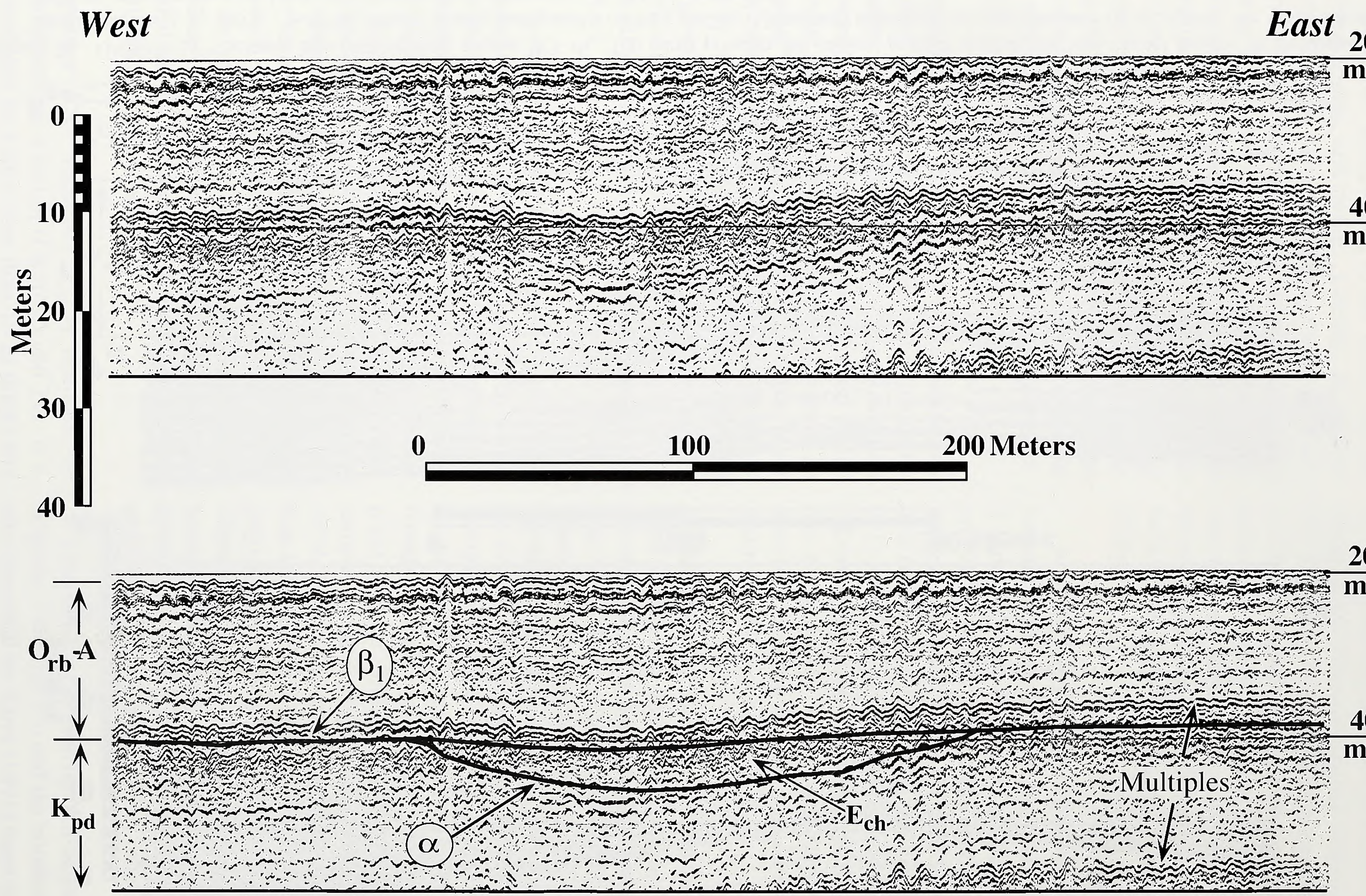


Figure 26. UNIBOOM™ seismic data from the eastern end of seismic section WS-17 (channel is at about 1245 on the time-event scale). Top panel presents the original graphic section; the lower panel illustrates unconformity surface β_1 with a channeled portion of the α surface preserved beneath it. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/second.

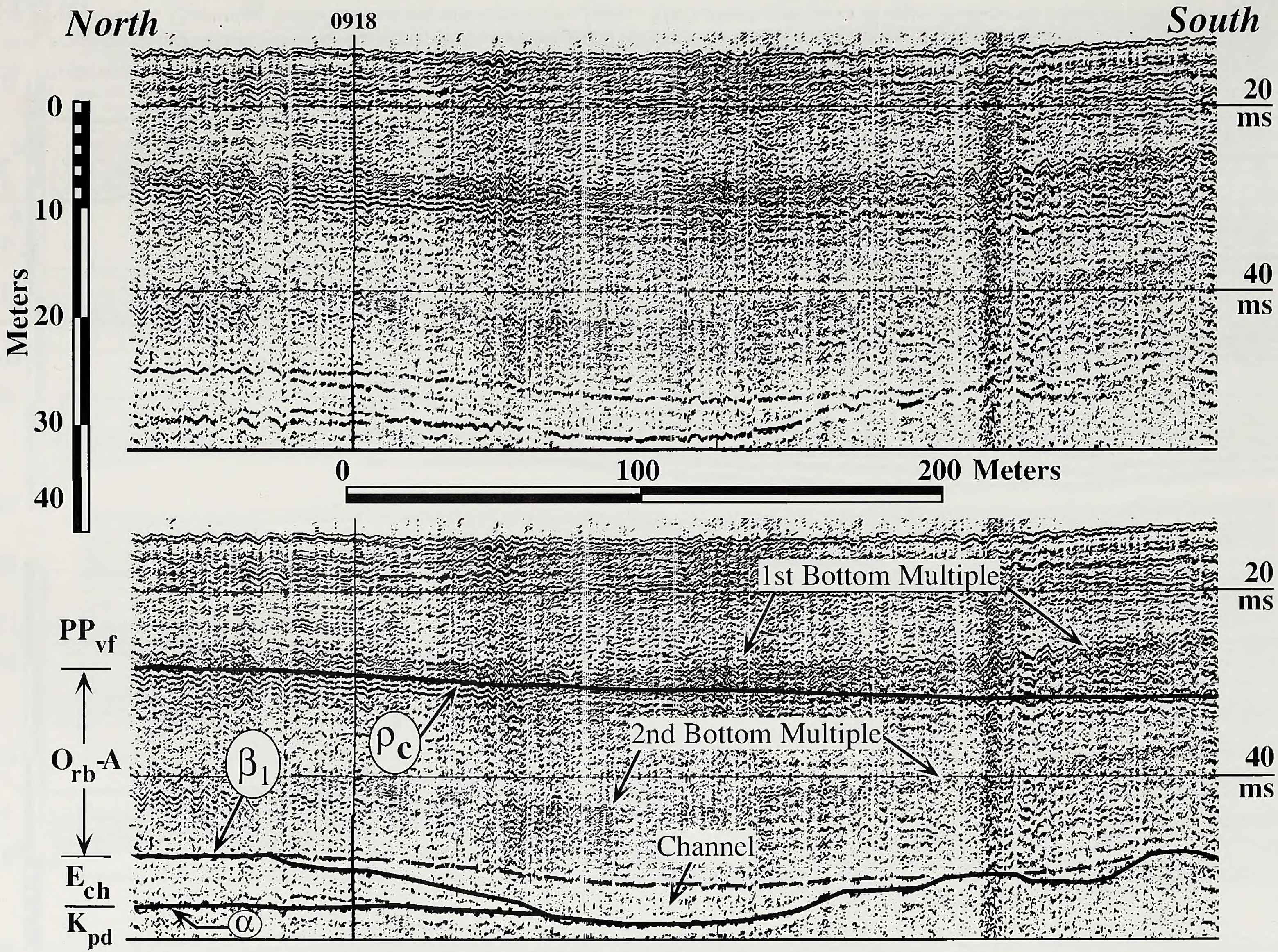


Figure 27. UNIBOOM ™ seismic data from seismic section WS-4. Top panel presents the original graphic section; in the lower panel, the positions of unconformity surfaces α, β_1, and ρ_c are labeled. Note the channel feature associated with surface β_1 which truncates sequence E_{ch} and causes sequence E_{ch} to pinchout to the south. Quaternary lithosomes are not annotated on the figure. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/sec.

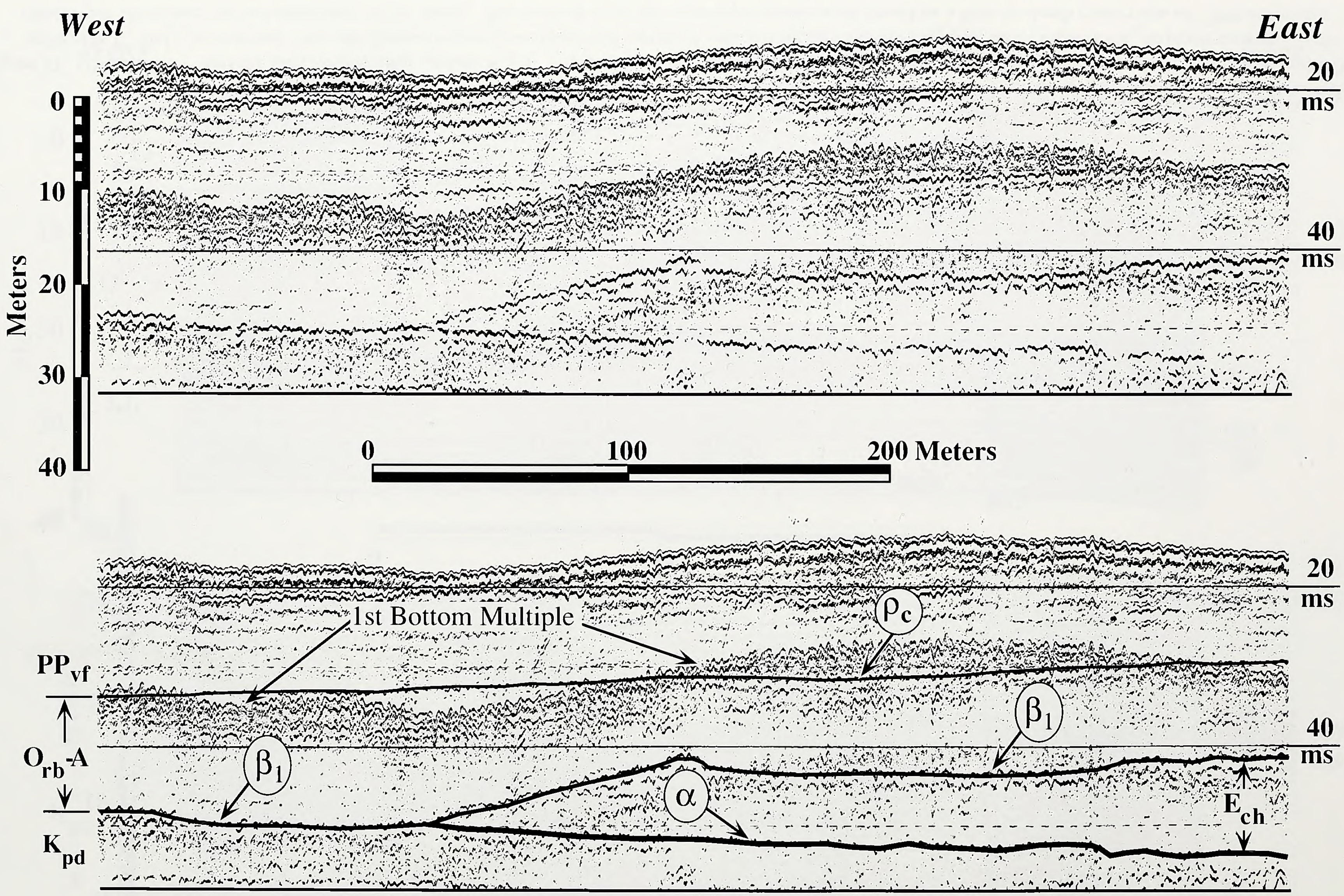


Figure 28. UNIBOOM™ seismic data from seismic section WS-8 (pinchout occurs at about 1384 on the time-event scale). Top panel presents the original graphic section; lower panel depicts the position of unconformity surfaces α and β_1. Note that these two surfaces merge from east to west, and sequence E_{ch} pinches-out as a consequence. Quaternary lithosomes are not annotated on the figure. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/second.

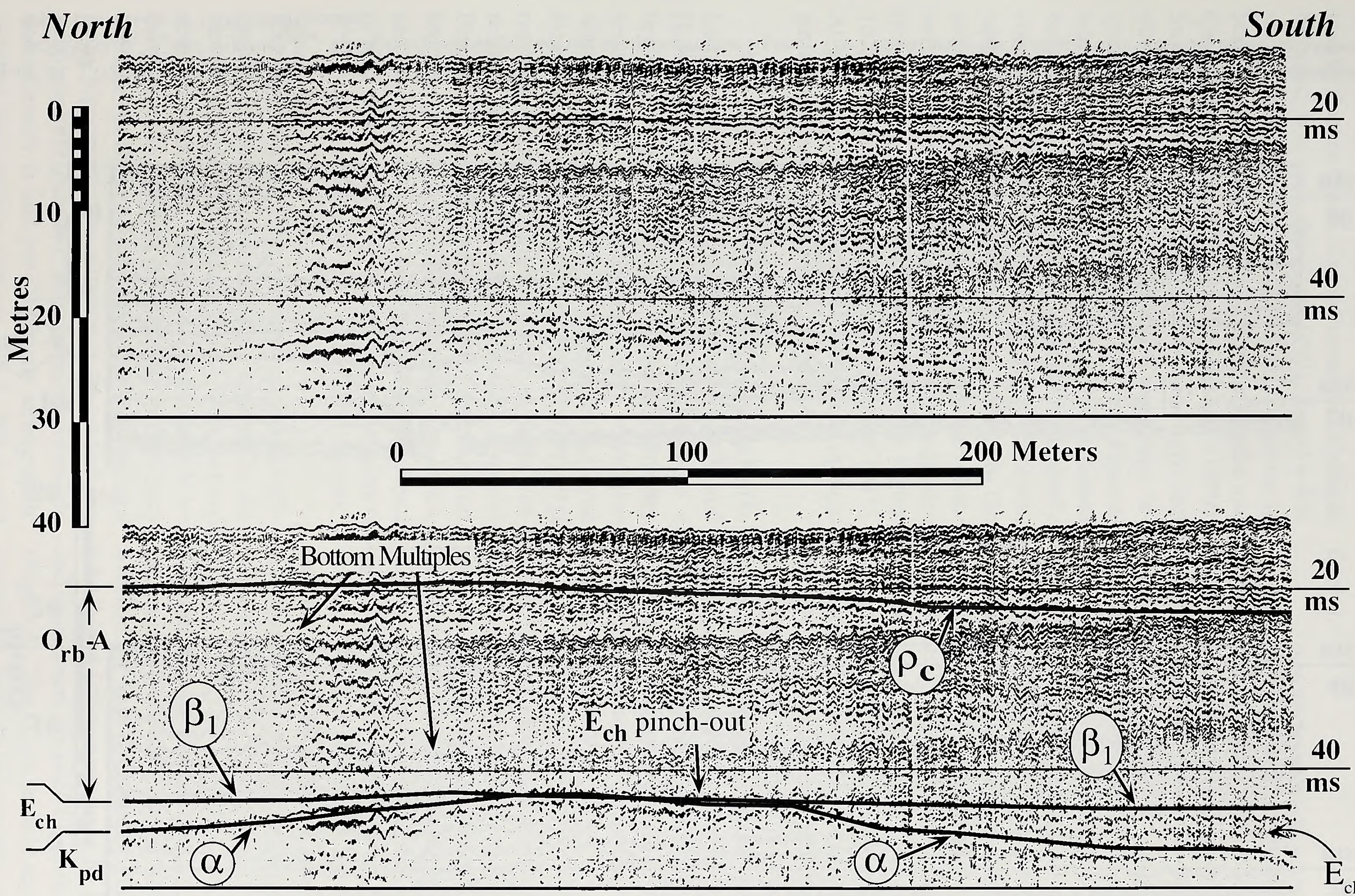


Figure 29. UNIBOOM™ seismic data from seismic section WS-4 (centered at about 0905 on the time-event scale). Top panel presents the original graphic section; lower panel delineates the position of unconformity surfaces α, β_1, and ρ_c. Note that the undulating relief of surface α, combined with the planar erosion by surface β_1, has produced a pinch-and-swell subcrop character for sequence E_{ch} on a localized scale. Quaternary lithosomes are not annotated on the figure. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/second.

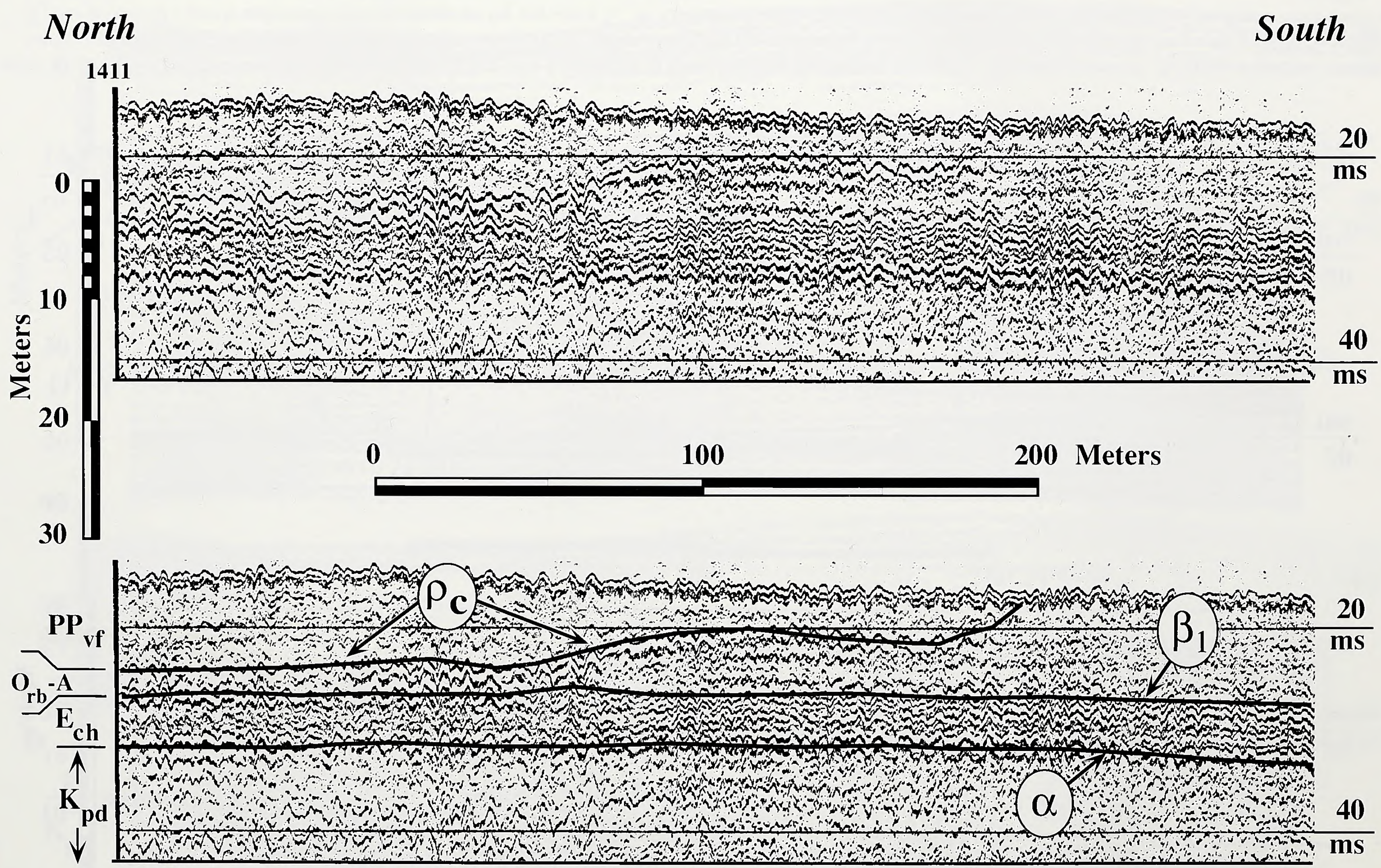


Figure 30. UNIBOOM™ seismic data from seismic section WS-3. Top panel presents the original graphic section; lower panel shows the position of unconformity surfaces α, β_1, ρ_c and sequence E_{ch}. Quaternary lithosomes are not annotated on the figure. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/second.

demonstrated that sequence E_{ch} is equivalent to the middle Eocene Castle Hayne Formation. It should be noted, however, that Zarra (1991) found a thin section of the Paleocene Beaufort Formation in borehole 52 sandwiched between the Peedee and Castle Hayne Formations. Meisburger (1979), Snyder (1982), Matteucci (1984), and Harris and others (1993) have also identified Paleocene sequences from the inner shelf off Cape Fear. Equivalent Paleocene sections were therefore expected below unconformity α. Although no laterally contiguous Paleocene sections were observed, equivalent-age sediments may be present in the suite of buried, irregular, and discontinuous channels commonly observed in the southern map area (for example, see seismic section WS-4 in Figure 10 between time-event markers 1108 and 1045). At present, these channel-fill features have been tentatively assigned to the E_{ch} sequence.

Vibracore samples from the E_{ch} outcrop belt in Long Bay were reported in Meisburger (1979) and Hoffman and others (1991) as consisting of a bryozoan biomicrudite. This lithofacies implies sequence E_{ch} is lithostratigraphically correlative with the Comfort Member of the Castle Hayne Formation (Ward and others, 1978). Zarra (1991) reported biostratigraphic information from correlative sections in onshore boreholes is sparse. Planktic foraminifera recovered from the Comfort Member in other onshore boreholes, in quarries, and in outcrops have been identified by Jones (1983) as indicative of the *Morozovella lehneri* (P12) and *Orbulinoides beckmanni* (P13) Zones.

Unconformity $\boldsymbol{\beta_1}$ The most conspicuous, high-amplitude, continuous, reflecting horizon in the survey area is unconformity β_1. This surface displays significant topographic relief which locally exceeds 5 meters (Figure 28). It dips east-southeast at about a 5 percent slope and truncates many topographic irregularities in the underlying stratigraphy (Figure 29). This surface also cuts into unconformity α and pre-Oligocene stratigraphic sections (see seismic sections WS-1, WS-4, and WS-9 among others in Figures 7, 4, and 10, respectively).

Unconformity β_1 is a very high-amplitude reflector (Figure 31) which does not crop out on the sea-floor in the map area (Figure 4). It surfaces in eastern Long Bay beneath the western margin of the Quaternary cape-retreat massif marked by Frying Pan Shoals (Snyder, 1982).

In many areas, the internal reflectors of the overlying Oligocene sequence downlap onto unconformity β_1 (see seismic sections WS-4 and WS-11 in Figures 10 and 17, respectively). Hence, this unconformity represents both an erosional surface (truncates pre-Oligocene sections and unconformities) and a downlap surface. Also, numerous channels have been identified directly underlying the β_1 unconformity surface (Figure 27 is an example). These channels may represent paleo-fluvial features, but the channel walls may also represent severed segments of unconformity α (Figure 32 depicts a good example). Because these features are discontinuous, the stratigraphic position of the channel-fill can not be determined from the seismic data alone.

Seismic expression of the β_1 unconformity as a downlap surface implies it represents a condensed section. Yet, this surface truncates the underlying stratigraphy. The latter serves to testify that β_1 is not a typical condensed section formed by sediment starvation (Vail and others, 1984; Loutit and others, 1988). Rather, it is an erosional marine surface buried by seaward progradation of the siliciclastic sand wedge comprising the overlying sequence (O_{rb}-A).

Sequence $\boldsymbol{O_{rb}}$***-A*** Sequence O_{rb}-A crops out across the entire survey area except where it is locally overlain by thin Quaternary lithosomes (ISSS, LSAS, and LSL) or replaced by Plio-Pleistocene and Quaternary channel-fill units PP_{vf} and PFCF (Figure 4). The O_{rb}-A seismic sequence is characterized by weak to moderately strong, clinoform

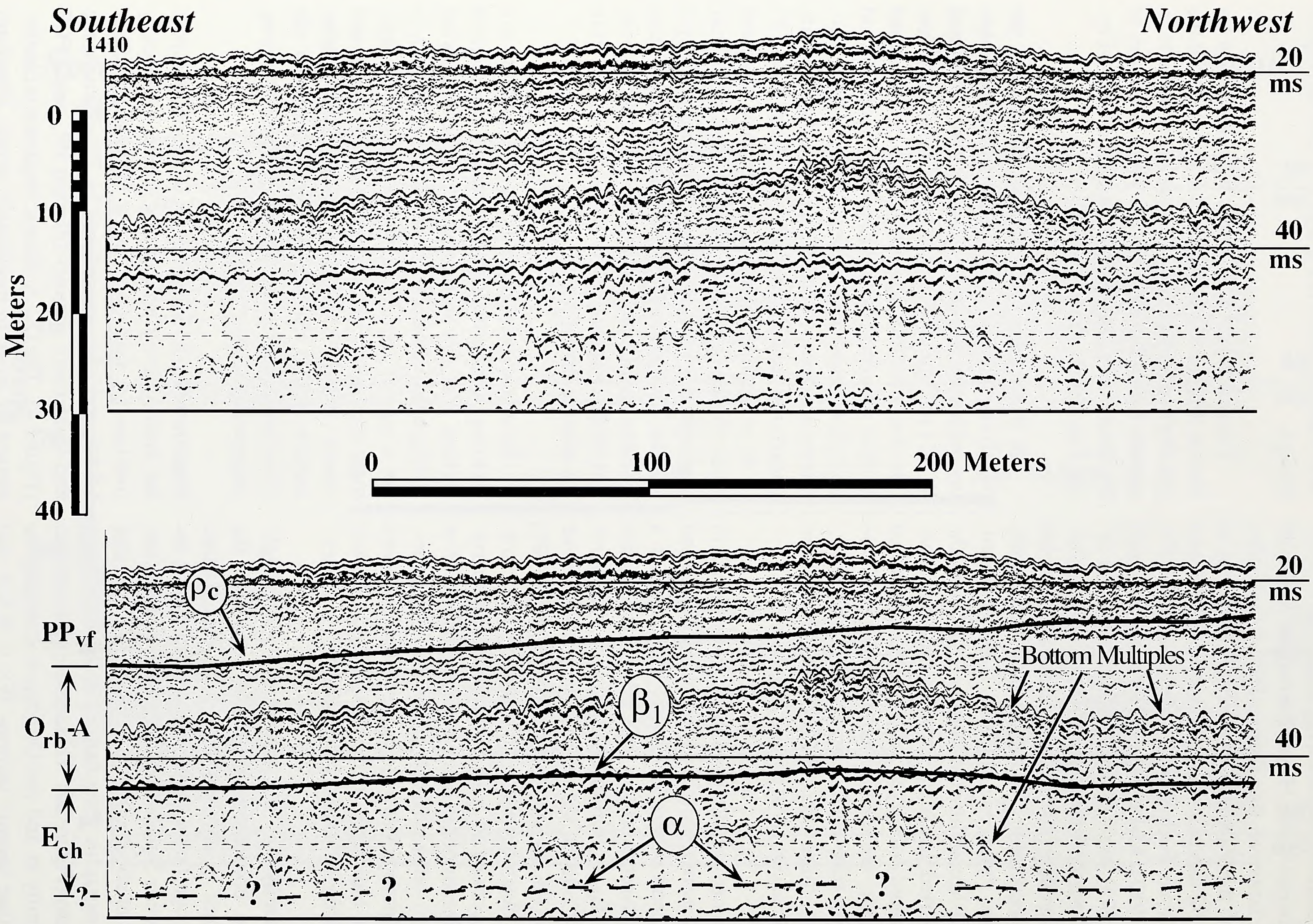


Figure 31. UNIBOOM™ seismic data from seismic section WS-9. Top panel presents the original graphic section; lower panel shows the positions of several multiples, regional unconformity surfaces α, β_1, and ρ_c. Note the high amplitude of unconformity β_1. Quaternary lithosomes are not annotated on the figure. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/second.

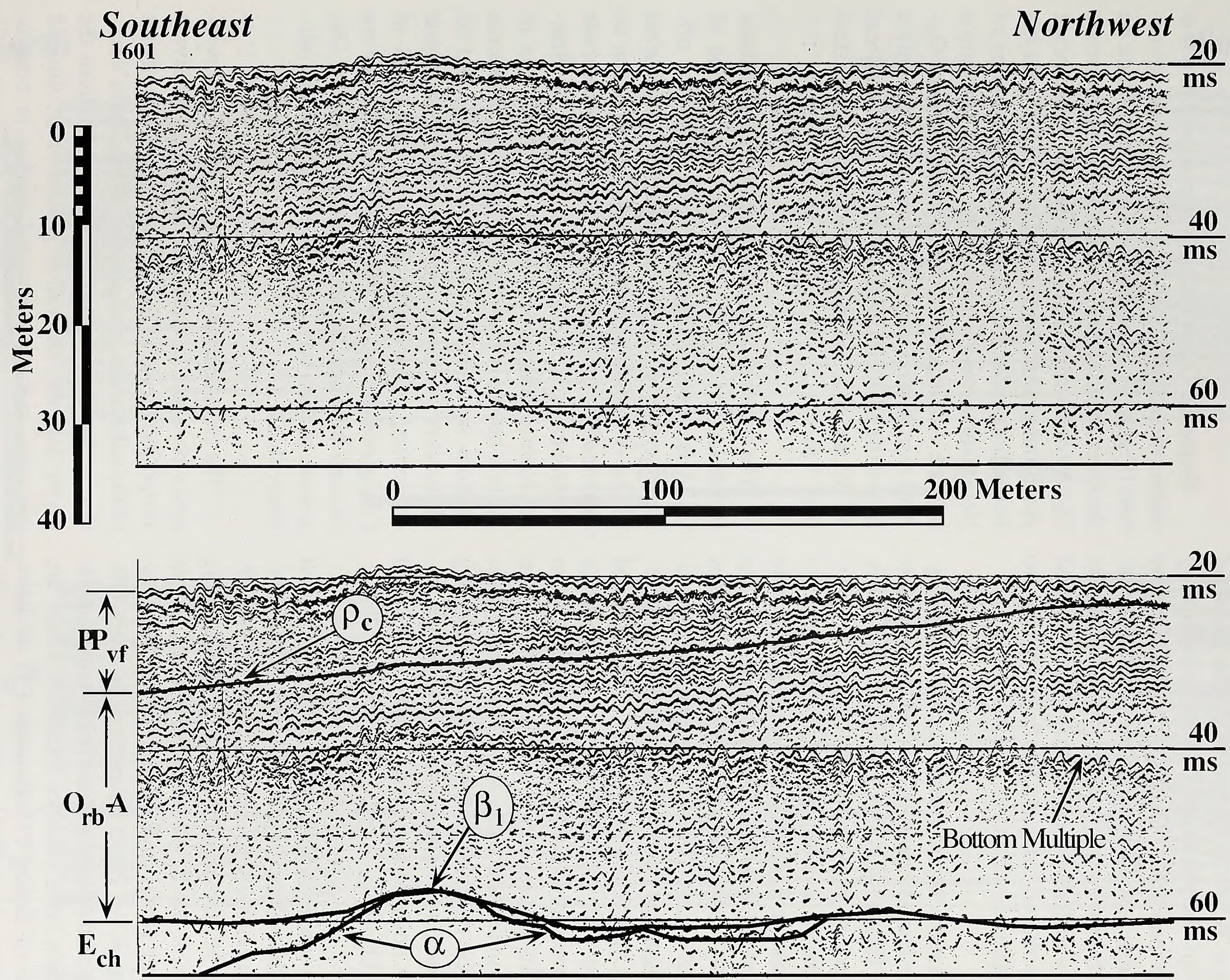


Figure 32. UNIBOOM™ seismic data from seismic section WS-11. Top panel presents the original graphic section; lower panel depicts the position of unconformity ρ_c and surface β_1 with related channel-like features. Note the internal reflection character of sequence O_{rb}-A. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/second.

reflectors prograding to the east-southeast (downdip). They commonly terminate in a downlap fashion onto reflector/unconformity β_1 (see seismic section WS-9 in Figure 15). The physical character of the clinoforms varies significantly within the map area. They are characterized by high-frequency, weak- to moderate-amplitude continuous reflectors in Figure 32. Figure 33 depicts a markedly different seismic facies characterized by infrequent, relatively continuous, moderate- to strong-amplitude reflectors.

Correlations to the vibracores located in Figure 2 have demonstrated sequence O_{rb}-A consists chiefly of fine- to very fine grained, well- to very well sorted, slightly calcareous, quartz sands. Locally, the sand is lithified (carbonate cement) and contains sparse, very fine grained dolomite rhombohedra (dolosilt). The lithified horizons are probably responsible for the internal clinoform reflections. Harts (1992) recognized an arenaceous Oligocene section in outcrops and boreholes in Onslow County which he considered correlative with the lower portion of the River Bend Formation (*Globigerina ampliapertura* Zone). This section may be a correlative onshore extension of sequence O_{rb}-A. Additional seismic data will be required to formally establish any physical or time-stratigraphic relationships between the onshore section of Harts (1992) and sequence O_{rb}-A.

Based upon planktic foraminifera identified from CERC vibracore 80 by Larry Zarra (personal communication), sequence O_{rb}-A is interpreted to be the seaward, chronostratigraphic equivalent of the River Bend Formation. Jones (1983) and Hazel and others (1984) have assigned the River Bend Formation an early Oligocene age based on the identification of planktic foraminifera from onshore localities which are indicative of Zones P19 through P21 of Blow (1969) . Again, however, the physical stratigraphic relationship of the calcareous, quartz sand facies (sequence O_{rb}-A) and the more typical moldic, biosparite lithofacies of the River Bend Formation found onshore has not been formally established.

Sequence O_{rb}-A thickens abruptly from a few meters to over 40 meters in an east-southeast direction (Figure 3). Although it is relatively thick on the inner shelf, Zarra's (1991) data depict sequence O_{rb}-A (or its equivalent) as thinning to an abrupt pinch-out against the middle Eocene Castle Hayne Formation under the present eastern shoreline of New Hanover and Brunswick Counties. As shown in Plate 1, Zarra (1991) recognized sequence O_{rb}-A (River Bend Formation in his report) in only a few of the adjacent coastal borehole sites (numbers 52, 59, and 61), and only as a very thin section (less than 3 m).

The apparent discrepancy between the onshore borehole stratigraphy (where the distribution of O_{rb}-A is shown as thin and limited) and the offshore seismic stratigraphy (where the distribution of O_{rb}-A is shown as thick and extensive) can be explained by the position of the onshore borehole sites relative to several large Plio-Pleistocene channel features mapped in Figure 4. Projection of Zarra's borehole locations to the offshore seismic sections indicates that holes 52, 59, 61, and 63 likely were located in areas where Plio-Pleistocene channeling removed as much as 20 meters of Oligocene section (see Plate 1). No boreholes were located between these channels where the Oligocene section would likely be present and relatively thick.

The cross section produced by linear, point-to-point borehole correlations depicts a relatively simplified image of the distribution and geometry of the subsurface stratigraphy. While Zarra's section is the only reasonable conclusion from the given data set, derivative groundwater, mineral resource, and environmental studies or conclusions based on such simplified modeling may have major errors and consequences. This example serves to point out the need to look beyond the

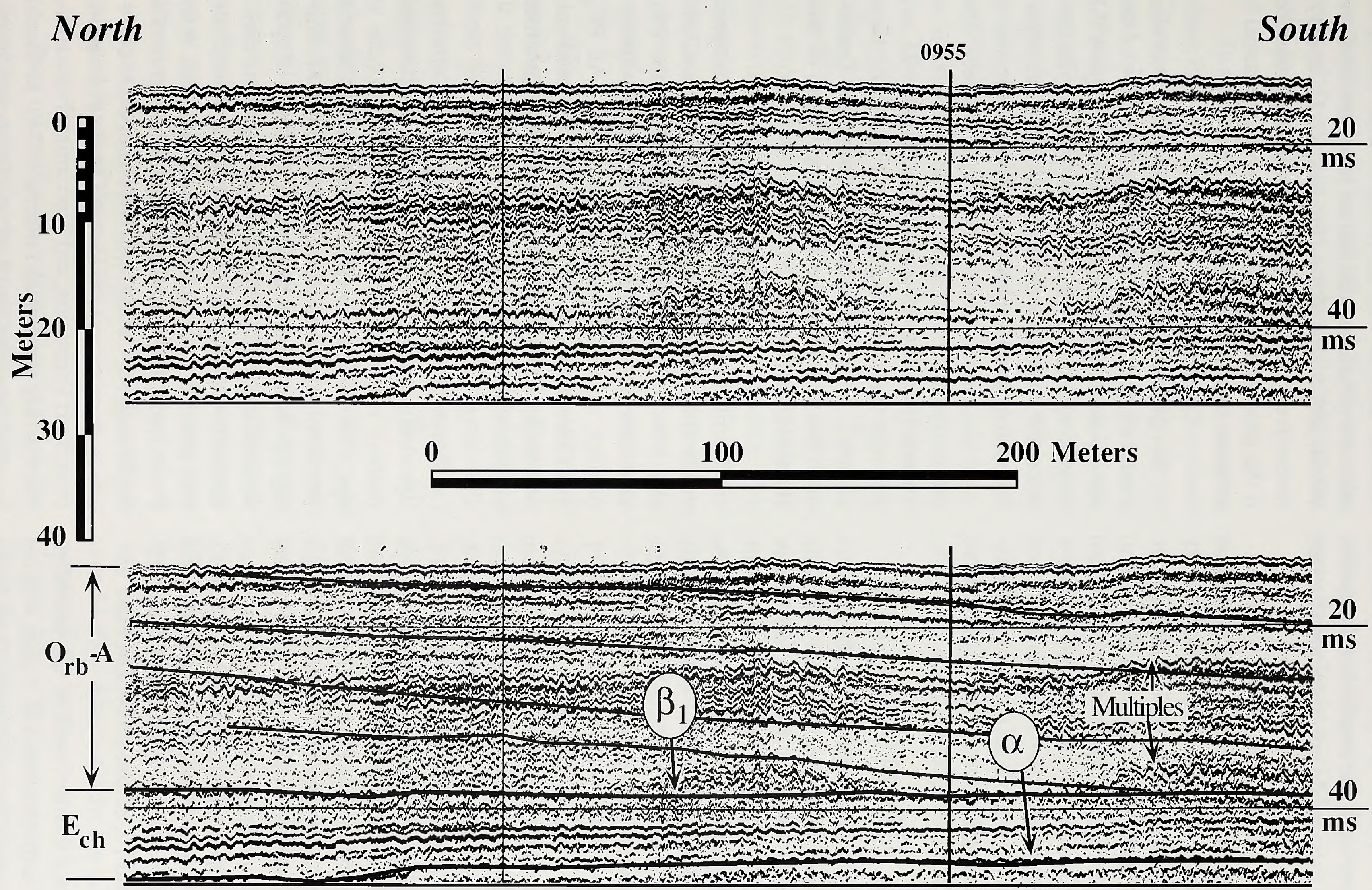


Figure 33. UNIBOOM™ seismic data from seismic section WS-4. Top panel presents the original graphic section; the lower panel depicts the position of unconformity surfaces α and β_1. Note that the internal reflectors of sequence O_{rb}-A downlap onto surface β_1. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/second.

immediate area of focus in a given study and to apply all practical tools and available information in attempting to extrapolate into areas with limited or no data.

A local discontinuity surface was identified within sequence O_{rb}-A on seismic section WS-11 (between time-event markers 1620-1630 in Figure 17). It crops out on the seafloor in the central portion of the map area (Figure 4). The limited nature of the seismic data set precludes tracing it laterally to evaluate its continuity and chronostratigraphic significance. It may be a regional unconformity, but it is presently considered a local diastem within sequence O_{rb}-A.

Lithosomes

Several distinct lithosomes were identified in the survey area as either unconformably overlying or filling channels cut into the outcrop belt of sequence O_{rb}-A (Figure 5). These lithosomes are not continuous features, and therefore cannot be classified as seismic sequences. However, they can be differentiated and mapped locally on the basis of the characteristics described below.

Plio-Pleistocene Valley-Fill (PP_{vf}) Four valleys greater than 3 km wide and greater than 15 m deep are cut into the Oligocene section (Figure 4; Plates 1 and 2; also see seismic sections WS-1, WS-4, WS-11, WS-15, and WS-16 in Figures 7, 10, 17, 21, and 22, respectively). These subbottom valleys are filled with Plio-Pleistocene age sediments and are herein referred to as Plio-Pleistocene valley-fill lithosomes. The valleys generally trend northwest to southeast and extend from the emerged coastal plain seaward beyond the limits of the seismic data set. The valley-infill seismic facies are primarily characterized by conformable and progradational fill geometries (see seismic sections WS-1 and WS-4 in Figures 7 and 10, respectively, and Plate 2).

The southwest channel wall of the southernmost valley-fill unit delineated in Figure 4 is not well defined; its position is inferred. Gaps in the seismic data as well as strong bottom multiples mask the position of this feature in seismic sections WS-4, WS-5, and WS-6 (Figures 10, 11, and 12, respectively). Additional seismic data are required if the geographic position of this major channel is to be accurately determined.

Several smaller-scale PP_{vf} lithosomes were also observed, particularly in the northern part of the survey area as illustrated in seismic sections WS-3 (Figure 9) and WS-15 (Figure 21). These smaller-scale PP_{vf} features are shallow, discontinuous lithosomes and likely resulted from the erosion of what was a much broader and deeper channel. The lithosome that is imaged at the intersection of seismic lines WS-15 and WS-16 (Figures 21 and 22) may have also been part of the same large channel. Erosional truncation during the Quaternary has left only the deepest portions of this channel in tact.

Many vibracores have penetrated the mapped valley-fills (Meisburger, 1979; Hoffman and others, 1991). These core sections depict the PP_{vf} lithosome as consisting of a variety of subtlely-distinct, sand-rich, skeletal lithofacies. All PP_{vf} infill facies are carbonate-rich, and the predominant skeletal components are bryozoans, fragmented molluscan shells, and barnacle plates.

Zarra (1991) has mapped a similar lithostratigraphic unit from boreholes and outcrops onshore which he ascribed as Plio-Pleistocene in age. He differentiated this section into several lithostratigraphic carbonate units at the L. M. Mining Pit in southern Brunswick County. Zarra's detailed section included three stratigraphic units. One unit was of early Pliocene age; the second unit was late Pliocene; and the third unit was early Pleistocene. Lithostratigraphic units recognized in the Brunswick County area which appear to correlate to these sequences are the Duplin Formation, Bear Bluff Formation, and Waccamaw Formation, respectively (DuBar and others, 1974). It should be noted, however, that the Plio-Pleistocene depos-

its could only be differentiated in the mine-wall sections and with the aid of good biostratigraphic control. In contrast, we have found the PP_{vf} lithologies to be internally indistinct.

In all borehole sections and vibracore samples, these Plio-Pleistocene bioclastic deposits have been "lumped" because they are lithologically similar and biostratigraphic indices have been mixed (Meisburger, 1979; Zarra, 1991; Hoffman and others, 1991). The mixing of Pliocene and Pleistocene index fossils is likely the product of multiple episodes of fluvial incision and subsequent channel-infill during the Pleistocene.

The PP_{vf} lithosome is not completely limited to valley-fill deposits. Within the southermost survey area, between time-events 1052 and 1135 on section WS-4 (Figure 10), the PP_{vf} lithosome exhibits an atypical, tabular geometry not appreciably different than that of the underlying E_{ch} sequence. This "bedded" PP_{vf} section may correlate to Plio-Pleistocene age sequences that Zarra (1991) was able to observe and discriminate in quarry exposures to the west of our study area in southern Brunswick County.

The relative age of the four major valley fills and their age relationship to the "bedded" section in the southernmost survey area cannot be defined from the present data set. They all overlie Oligocene sections and underlie Quaternary lithosomes.

Quaternary Lithosomes (LSL, LSAS, ISSS, and PFCF) The Quaternary section on the inner continental shelf is limited to the four lithosomes shown in Figure 5. Each lithosome was differentiated and mapped based on its present morphology and geographic position. The Quaternary lithosomes, in aggregate, are interpreted to be stratigraphically equivalent to the undifferentiated surficial sands of Zarra (1991).

The *Lower Shoreface Lithosome (LSL)* is distinguished solely by its geographic position. It represents the distal (lowermost) part of the modern shoreface (Figure 4). Figures 34 and 35 illustrate examples of the LSL.

Linear Shoreface-Attached Shoals (LSAS) are an extension of the LSL. The LSAS lithosome projects out onto the inner shelf and forms a linear topographic high which gradually diverges northeastward at an angle of approximately 25-40 degrees from the shoreline. These shoals are linear features, hundreds of meters wide and kilometers in length, with less than 5 meters of sea-floor relief (Figures 36 and 37). Their general distribution is reflected by the 10-meter bathymetric contour as shown by comparing Figures 2 and 4.

The anatomy of both the LSL and LSAS, as imaged by the seismic data (Figures 34 to 37), depicts these lithosomes as having an internal stratigraphy consisting of a series of channels and discontinuity surfaces. Hence, they are not modern depositional features. Instead, they appear to be the erosional remnants of partially preserved Pleistocene sections deposited during successive Quaternary sea-level fluctuations. These sections are presently being exhumed and consumed by active shoreface erosion.

The *Inner Shelf Sand Shoals (ISSS)* lithosome is detached from the lower shoreface. These shoal bodies are thin surficial features (less than 3 meters thick in Figures 38 and 39). ISSS likely represent the erosional remnants (outliers) of pre-existing LSAS lithosomes now stranded on the continental shelf. This is suggested by their juxtaposition to several areas of LSAS features as shown in Figure 4.

Figure 38 reveals the anatomy of one ISSS lithosome which features multiple cut-and-fill structures very similar in character to the internal seismic signature exhibited by LSL and LSAS (Figures 34-37). Alternatively, the seismic data have portrayed the anatomy of ISSS as reflection free (Figure 39). The transparent seismic facies is likely the product of the very thin nature of the ISSS

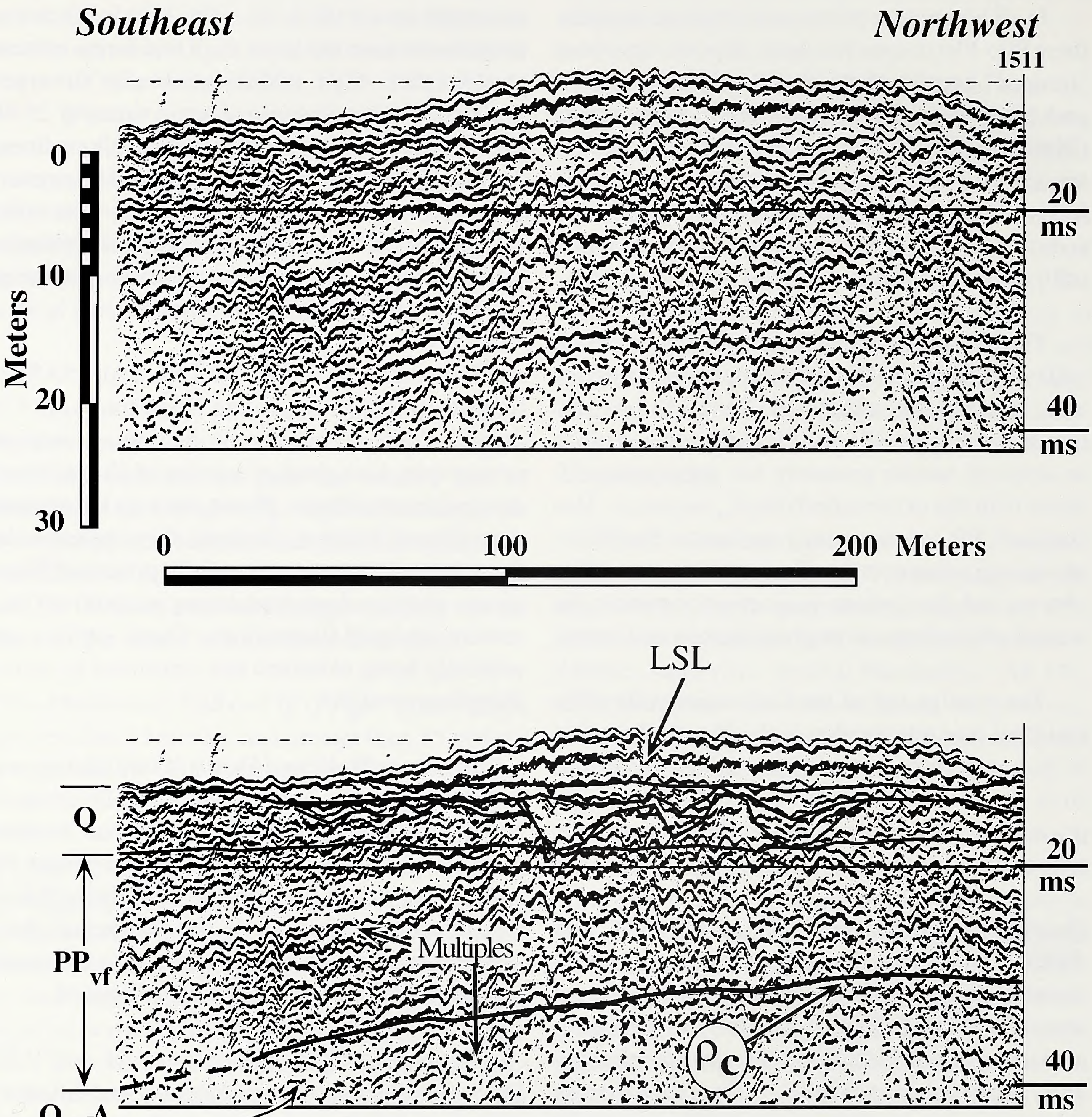


Figure 34. UNIBOOM™ seismic data from seismic section WS-9. Top panel presents the original graphic data; lower panel highlights channels and erosional surfaces characterizing the LSL. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/second.

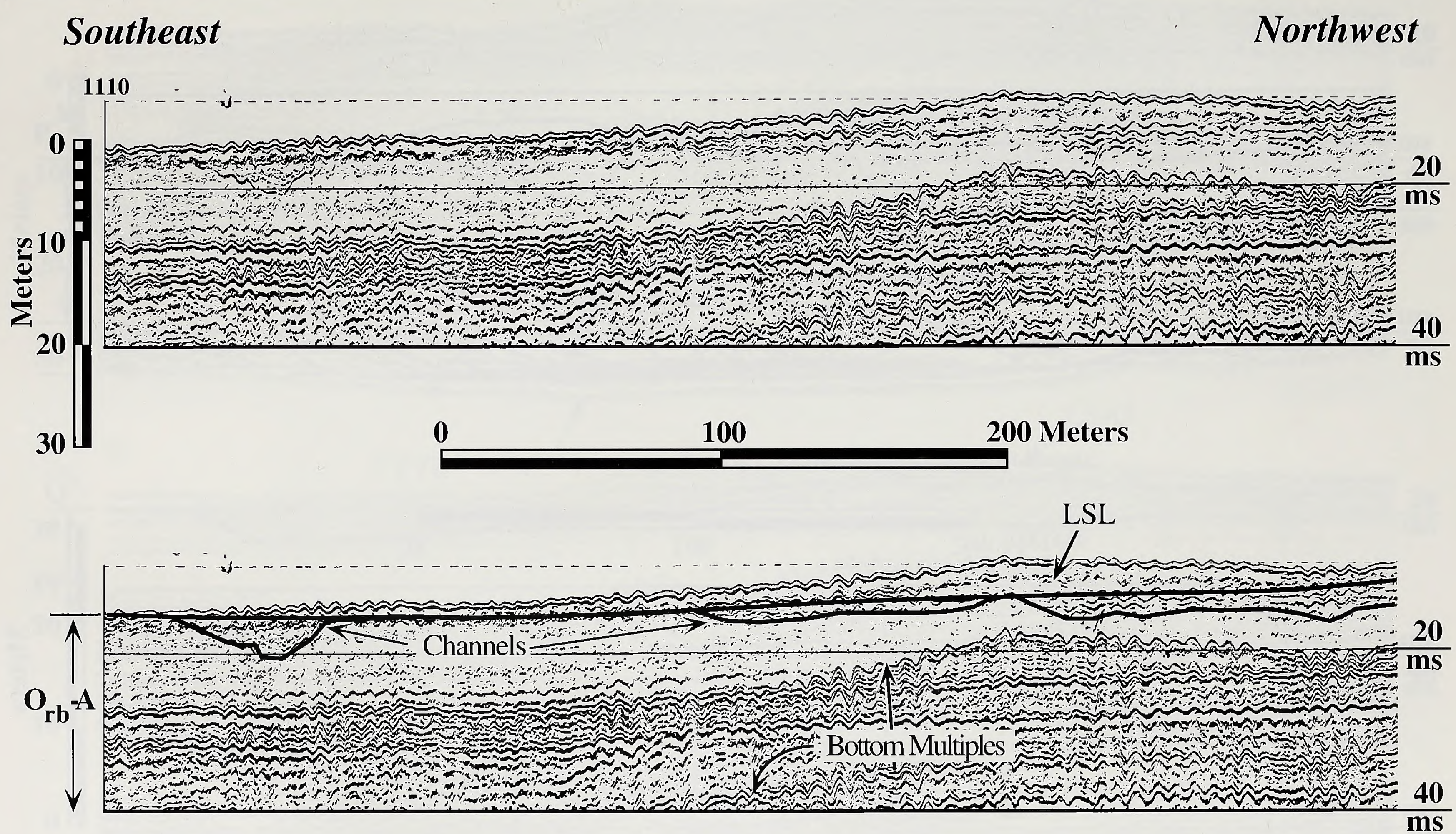


Figure 35. UNIBOOM™ seismic data from seismic section WS-14. Top panel presents the original graphic data; lower panel illustrates several channel features underlying the LSL. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/second.

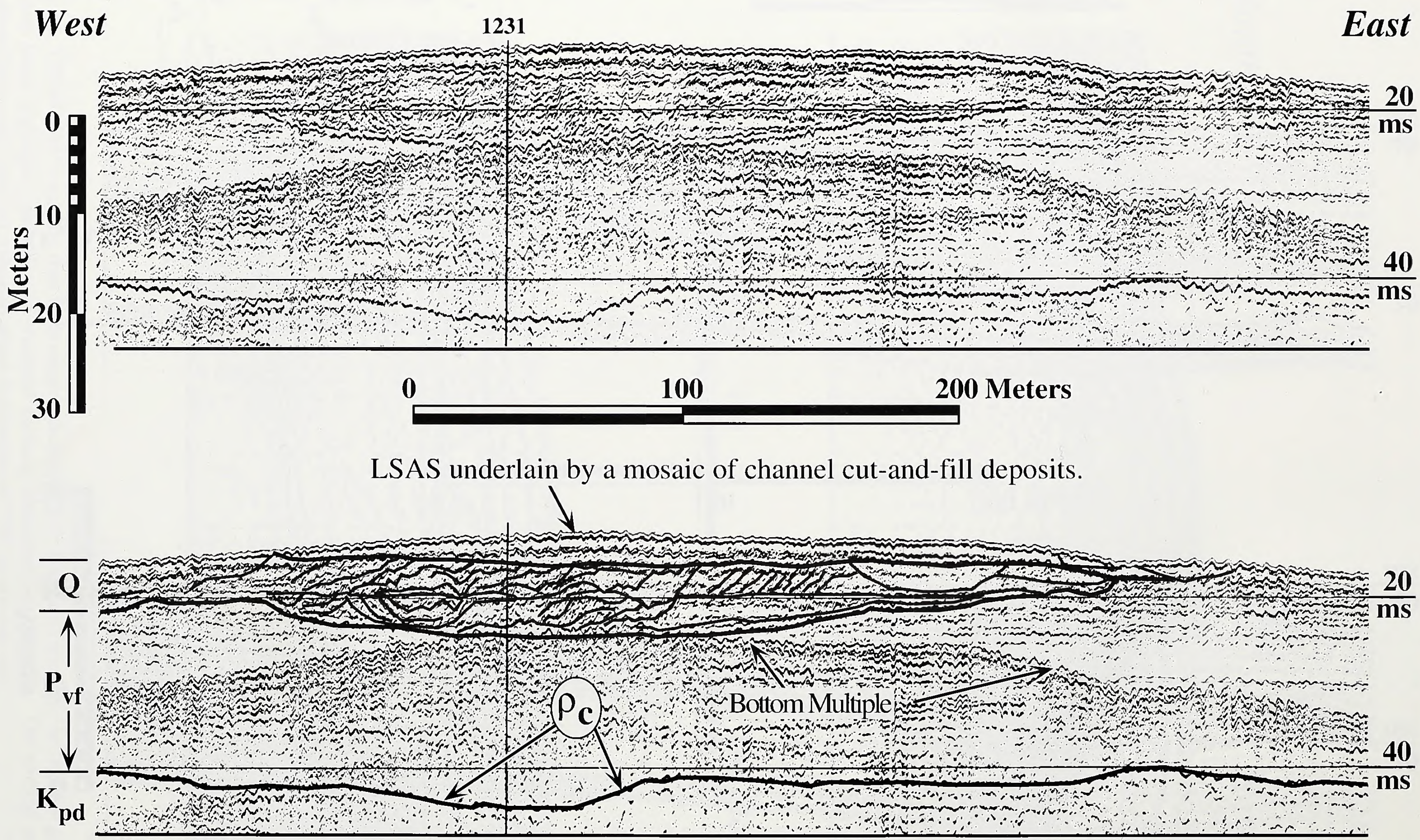


Figure 36. UNIBOOM™ seismic data from seismic section WS-6. Top panel presents the original graphic section; lower panel depicts the anatomy of the LSAS, as well as the position of unconformity ρ_c. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/second.

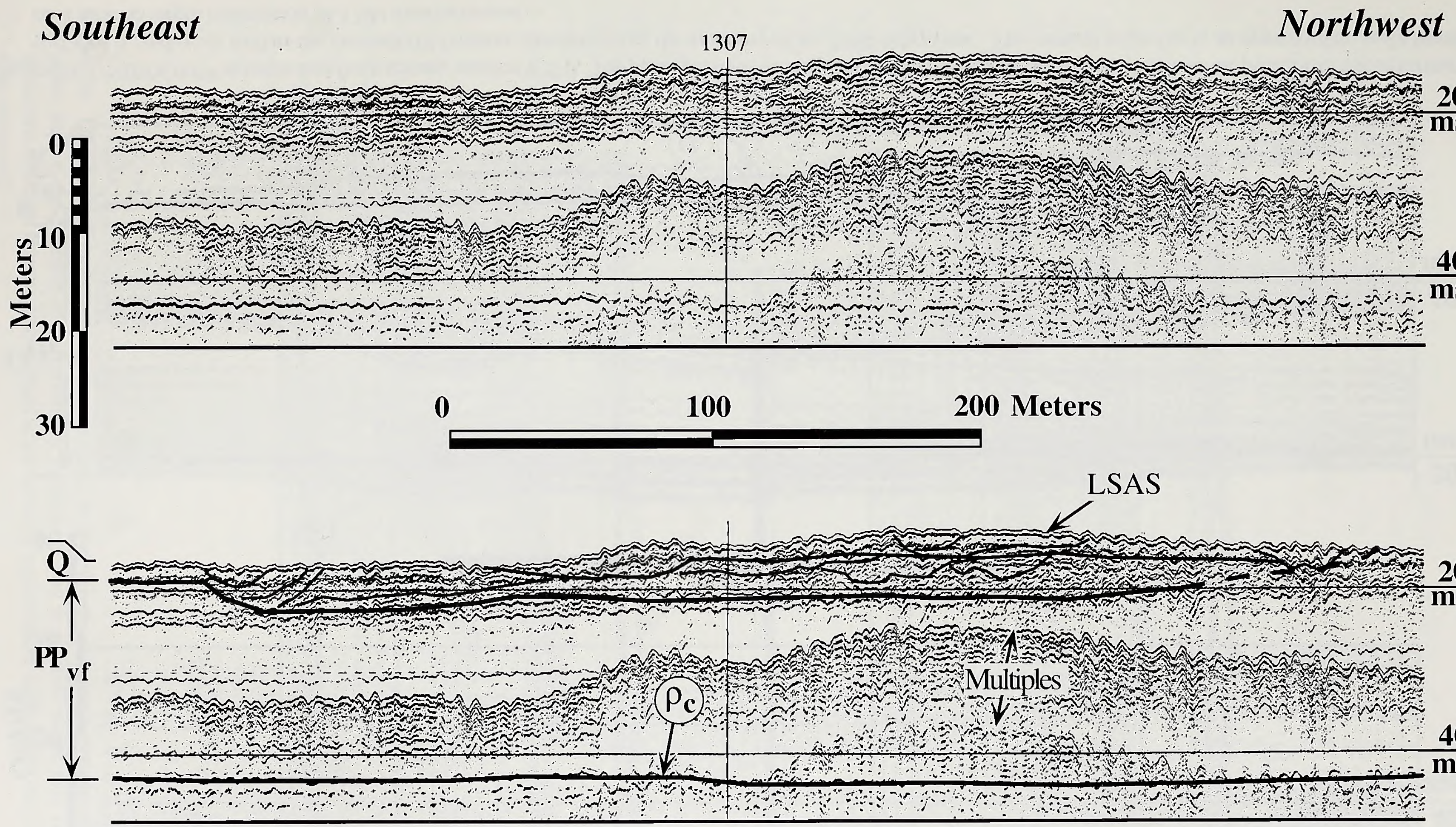


Figure 37. UNIBOOM™ seismic data from seismic section WS-7. Top panel presents the original graphic section; lower panel depicts the cut-and-fill reflection geometries which characterize the anatomy of the LSAS. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/second.

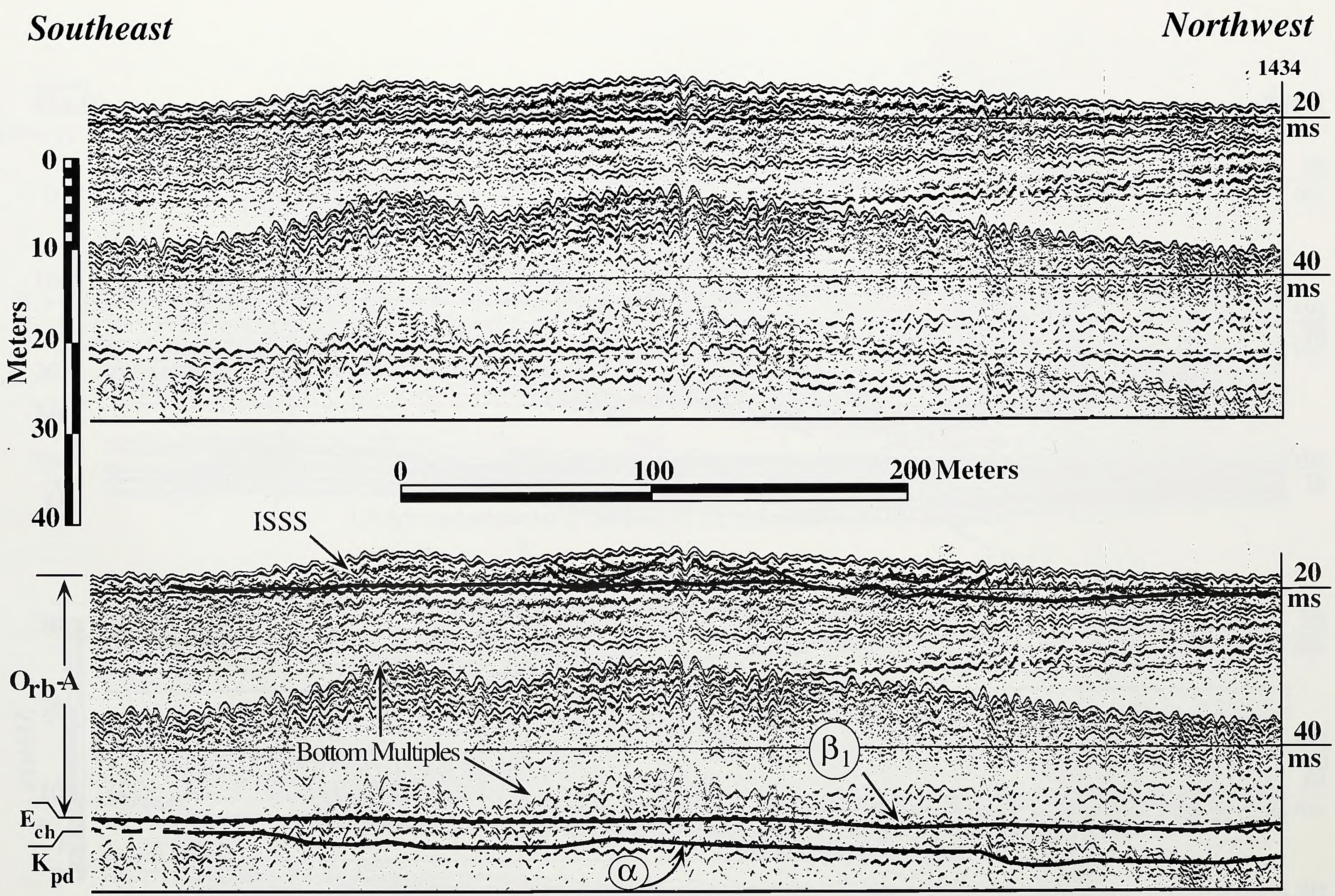


Figure 38. UNIBOOM™ seismic data from seismic section WS-9. Top panel presents the original graphic section; lower panel illustrates the position of unconformity surfaces β_1 and α, as well as the cut-and-fill features characterizing the anatomy of an ISSS lithosome. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/second.

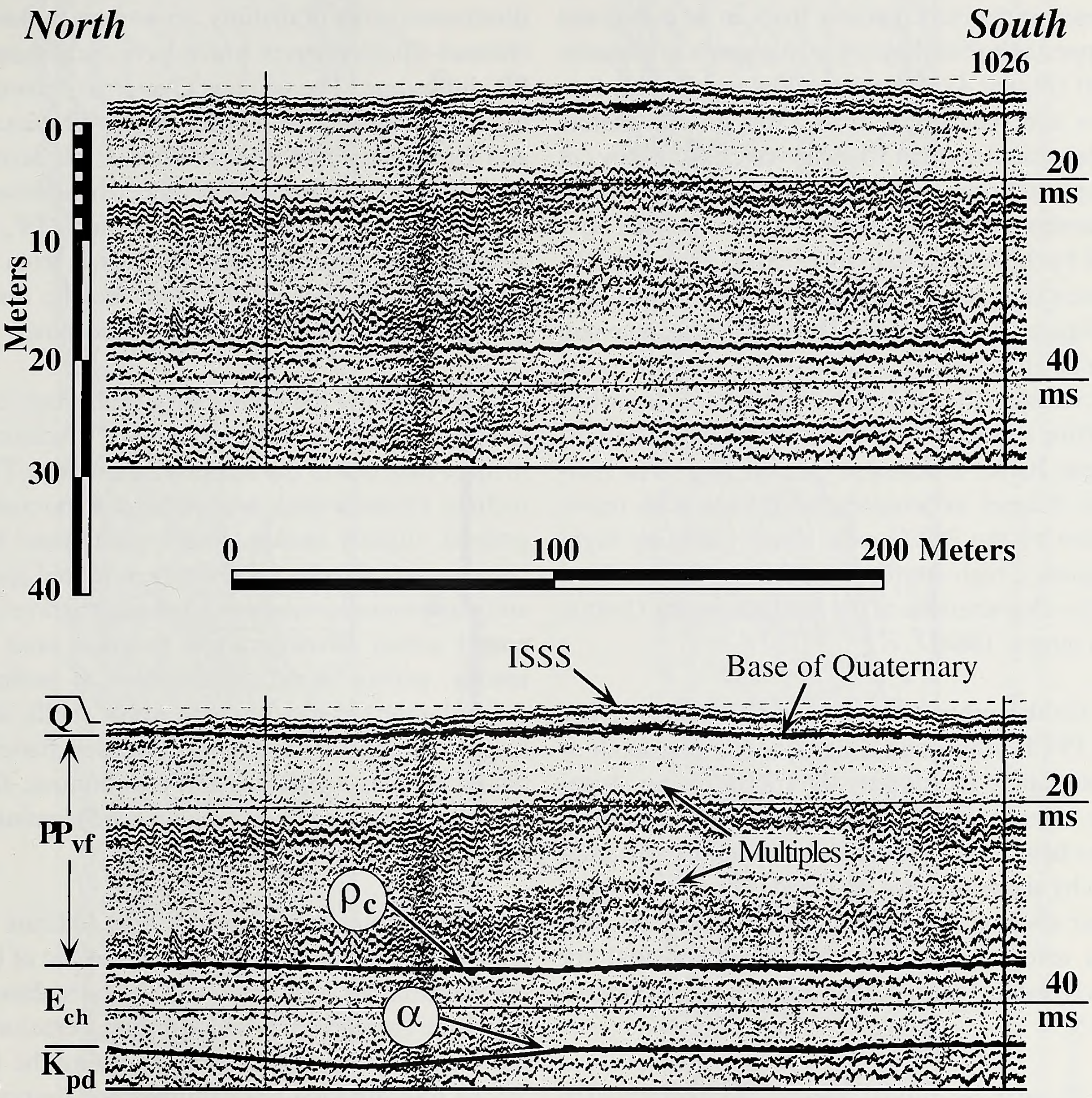


Figure 39. UNIBOOM™ seismic data from seismic section WS-4. Top panel presents the original graphic section; lower panel depicts the position of unconformity surfaces ρ_c and α, as well as the thin and transparent nature of an ISSS lithosome off Kure Beach. The vertical scale bar is an approximate scale based on a time to-depth conversion of 1700 meters/second.

lithosome. Any internal reflectors would be difficult to image because they lie below the working vertical-resolution of the seismic tool.

Paleo-Fluvial Channel-Fill (PFCF) lithosomes consist of distinct channels that can be traced and mapped as buried thalwegs across parts of the inner shelf (Figure 4). These shallow, subbottom features are typically narrow (100 to 300 meters wide), thin (less than 10 meters thick), and they cut steeply into the pre-Quaternary sections. PFCF lithosomes are very common within the area covered by the seismic data set (Figures 7 through 23). Some examples of PFCF lithosomes are illustrated in Figures 40 through 45. The PFCF lithosomes are similar in geometry and seismic character to the siliciclastic-filled paleo-fluvial channels described by Hine and Snyder (1985) from the inner shelf off Bogue Banks in northern Onslow Bay. The multiple channel excavation-and-fill episodes represented by the PCFC were likely paced by high-frequency, high-amplitude, glacioeustatic sea-level cycles characteristic of the late Quaternary (Imbrie and others, 1984).

Unlike other near-surface Quaternary units, the PFCF lithosomes extend below the depth of stratigraphic incision by the transgressing shoreline. Hence, basal portions of these channel features have a high potential for escaping consumption by shoreface erosion during shoreline retreat. Their abundance on the adjacent continental shelf is a testimony to their enhanced potential for survivorship (Figure 4 and maps in Hine and Snyder, 1985).

These paleo-fluvial features are interpreted to represent lowstand stream incision and fluvial deposition, followed by transgressive estuarine to backbarrier infill. A mud-rich estuarine infill facies was recovered in vibracore 87 from the channel that is illustrated in Figure 40 and seismic section WS-16 (Figure 22). However, not all the PCFC lithosomes contain only Quaternary fluvial or estuarine lithologies.

Multiple episodes of fluvial incision and subsequent channel-fill during the Quaternary has promoted the reworking of older index fossils from underlying units. These materials are then mixed into the Quaternary channel-fill facies. Figure 41 illustrates a series of shallow, accretional to chaotic channel-fill geometries which have incised into a PP_{vf} lithosome. The younger Quaternary channeling has facilitated the mixing of Plio-Pleistocene and Quaternary materials. Without the seismic data to demonstrate that distinct, smaller-scale channel-fill facies are cut into the larger PP_{vf} incised valley, vibracore data recovered from the Quaternary channel would likely not be distinguished from the underlying PP_{vf} lithosome.

Collectively, the Quaternary lithosomes consist of a variety of lithologies; most of which occur in more than one of the mapped lithosomes. They include: (1) moderately well sorted, fine- to coarse-grained, slightly muddy, shelly quartz sand with common whole pelecypod shells, echinoid spines and some rounded to subrounded quartz gravel; (2) poorly sorted, coarse-grained, biogenic sand; (3) muddy, poorly sorted, shelly, fine- to medium-grained quartz sand with large whole shells, shell fragments, and trace amounts of rounded, flattened quartz pebbles; (4) clean, non-fossiliferous, fine- to medium-grained quartz sand; and (5) laminated silty muds with few shells.

The seismic and vibracore data indicate the Quaternary lithosomes consist of a mosaic of barrier, backbarrier, estuarine, and fluvial sediments which are currently exposed to physical erosion on the sea floor. Persistent erosion during the Holocene transgression has exhumed and destroyed most of the the Quaternary stratigraphy described by Zarra (1991) and mapped onshore as undifferentiated "surficial sands". Only a few laterally discontinuous lithosomes have escaped total consumption by the transgressing shoreface. These lithosomes either lie offshore as outliers (ISSS), are preserved as buried, elongate, paleo-fluvial channel-fills (PFCF), or are presently under attack

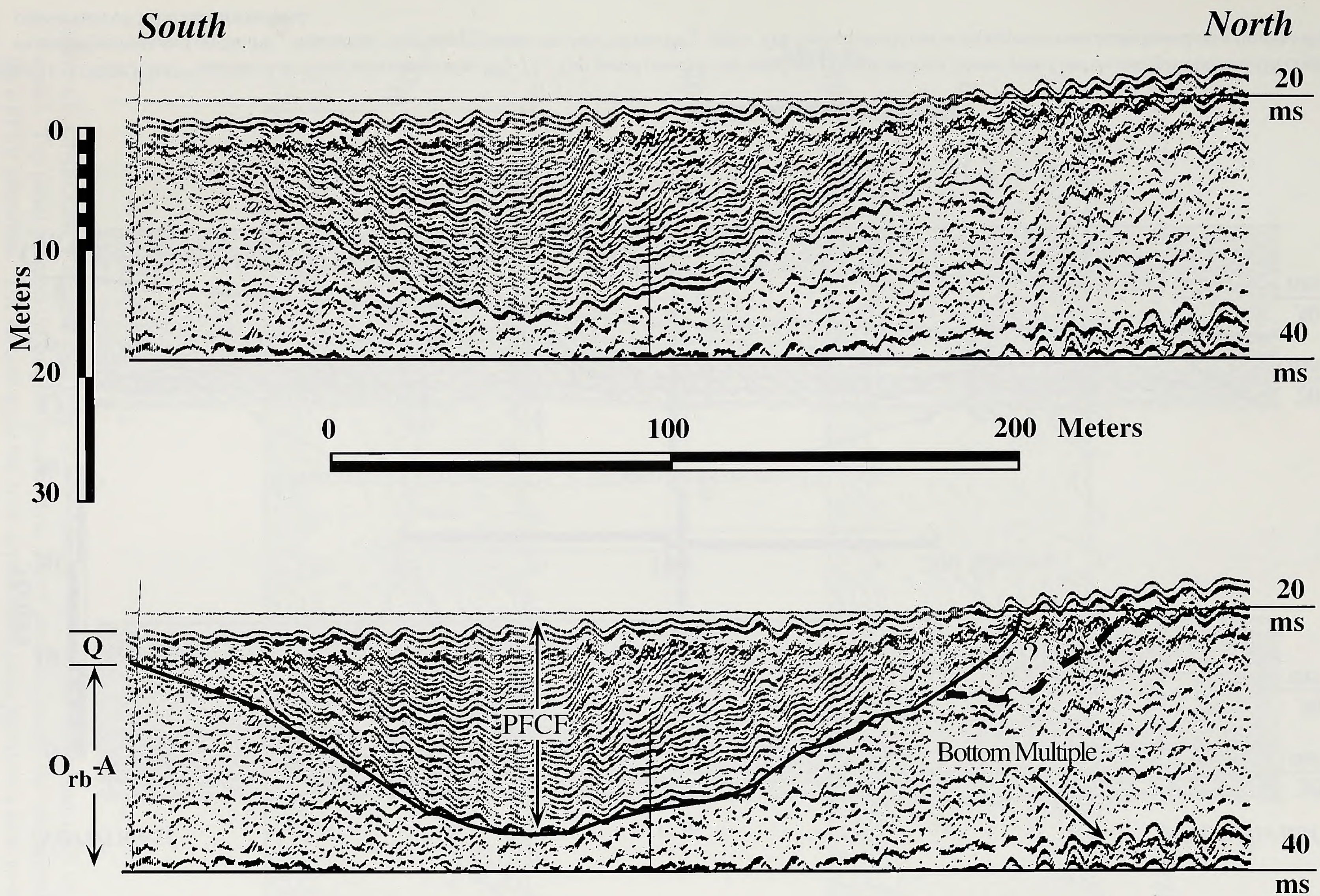


Figure 40. UNIBOOM™ seismic data from seismic section WS-16 (channel is centered at approximately 1231 of the time-event scale). Top panel presents the original graphic data; lower panel delineates the interpreted channel walls for a PFCF lithosome. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/second.

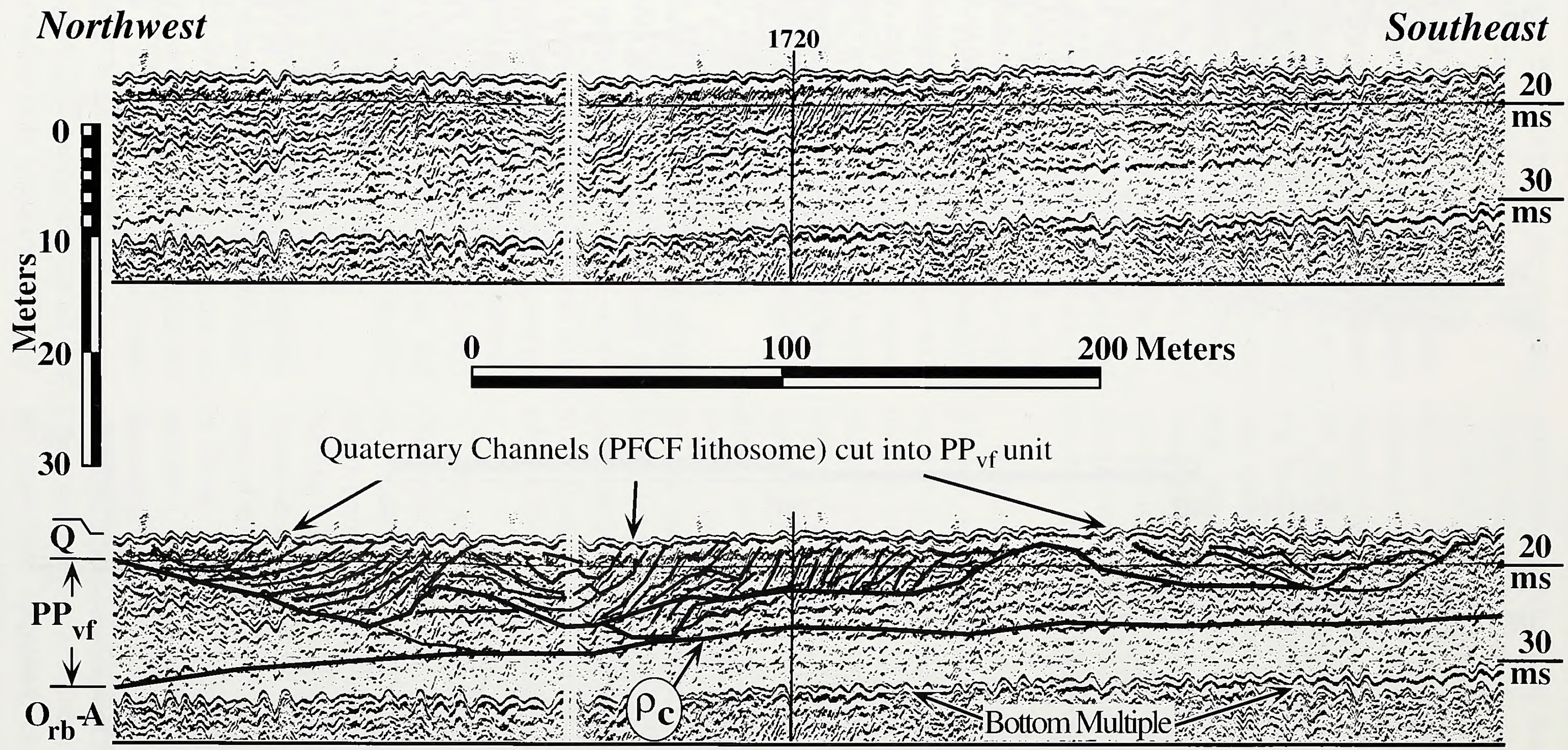


Figure 41. UNIBOOM™ seismic data from seismic section WS-11. Top panel presents the original graphic section; lower panel shows mutiple cut-and-fill channel events superimposed on the PP_{vf} lithosome. Surface ρ_c marks the base of the PP_{vf} unit. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/second.

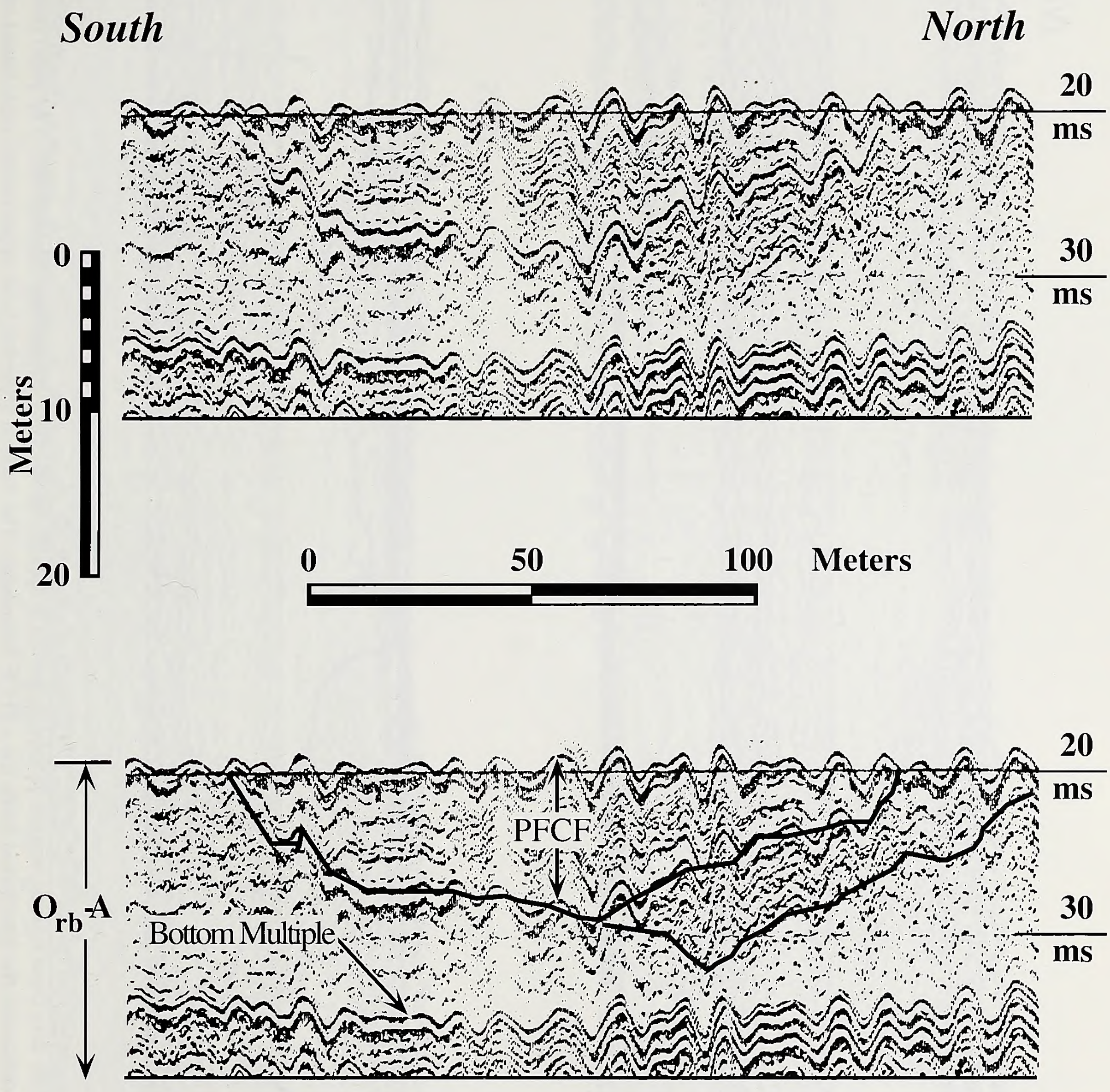


Figure 42. UNIBOOM™ seismic data from seismic section WS-1 (centered at about 1248 on the time-event scale). Top panel presents the original graphic data; lower panel delineates the interpreted channel walls for a PFCF lithosome. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/second.

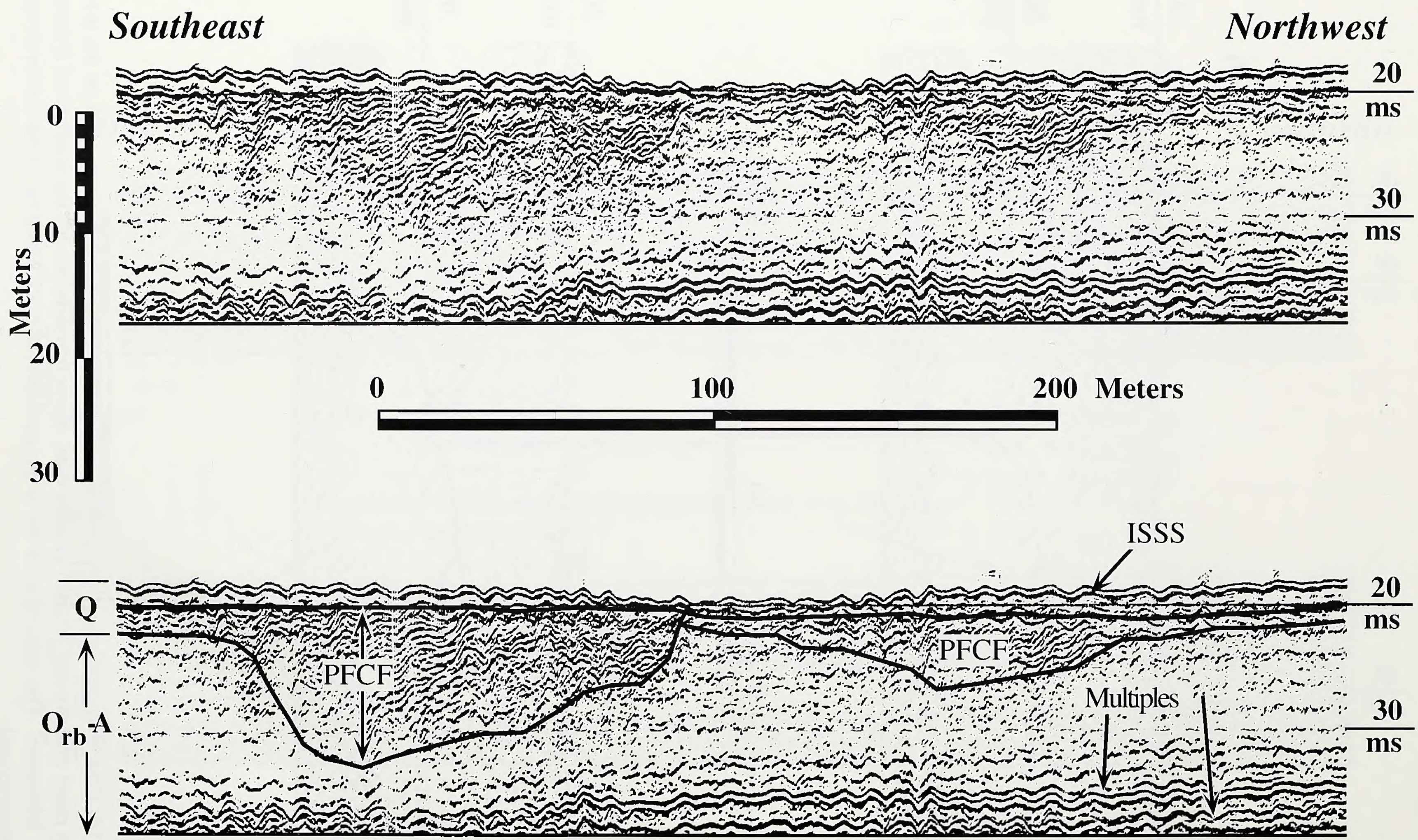


Figure 43. UNIBOOM™ seismic data from seismic section WS-14 (centered at approximately 1047 on the time-event scale). Top panel presents the original graphic data; lower panel delineates the interpreted walls for a PFCF lithosome. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/second.

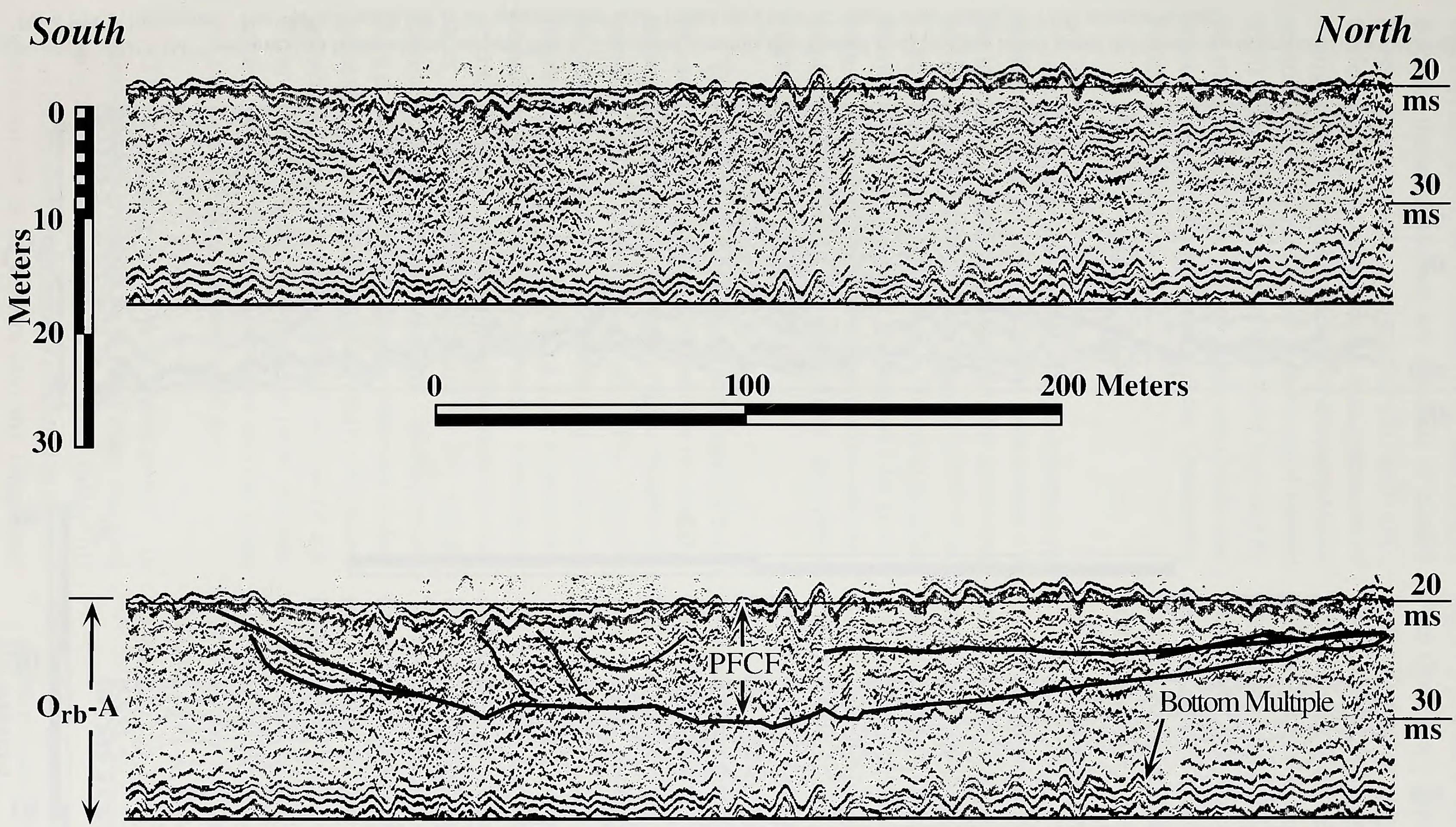


Figure 44. UNIBOOM™ seismic data from seismic section WS-1 (centered at approximately 1213 of the time-event scale). Top panel presents the original graphic data; lower panel delineates the interpreted channel walls for a PFCF lithosome. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/second.

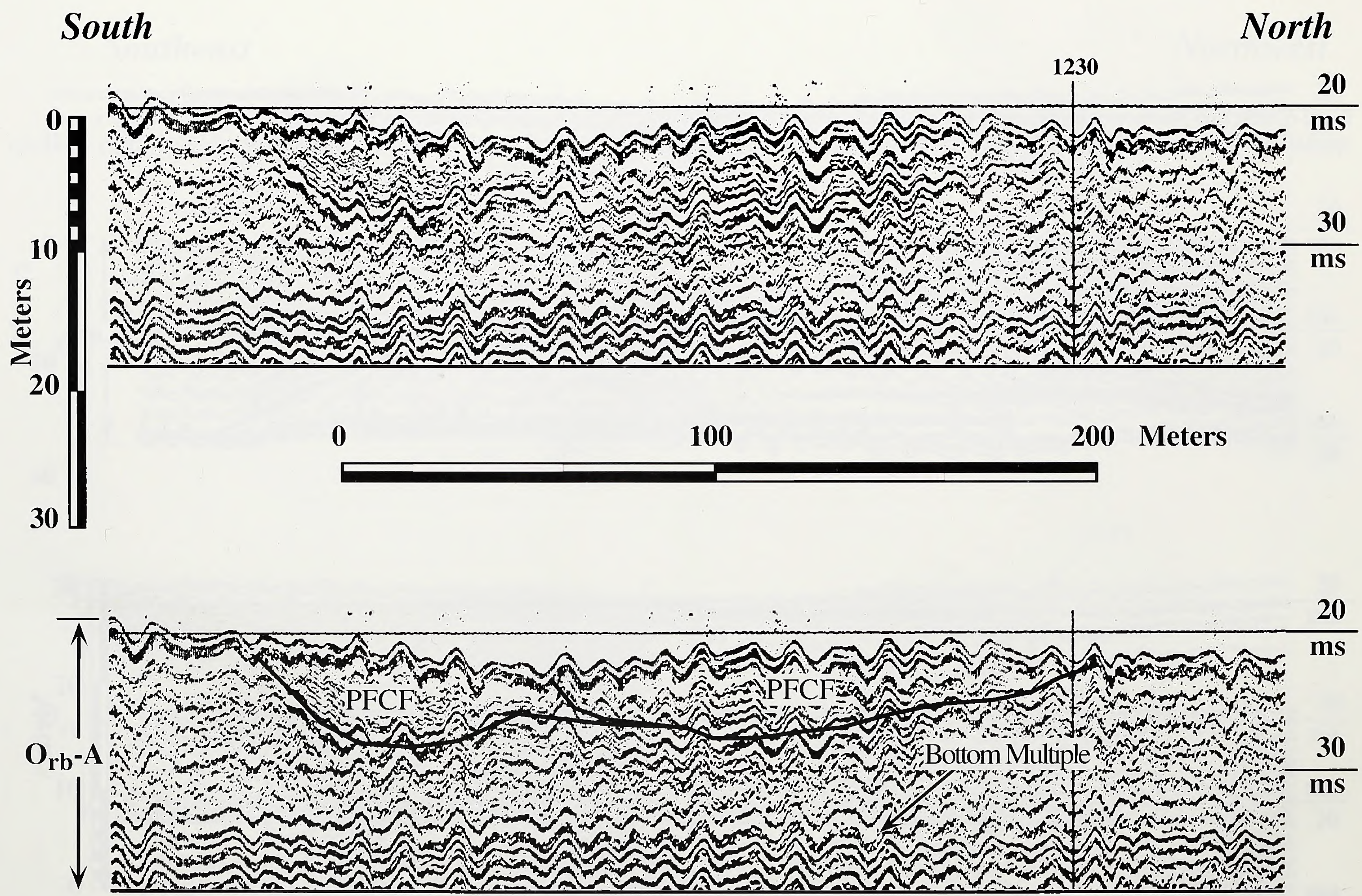


Figure 45. UNIBOOM™ seismic data from seismic section WS-1. Top panel presents the original graphic data; lower panel delineates the interpreted channel walls for a PFCF lithosome. The vertical scale bar is an approximate scale based on a time-to-depth conversion of 1700 meters/second.

by shoreface erosional processes (LSL and LSAS). Because these lithosomes are a mosaic of paralic facies, they are lithostratigraphically indistinct. Collectively, they represent an amalgamation of stratigraphic packages produced by the partial preservation of many transgressive and coastal system tracts alternately forced landward and seaward by the multiple, high-frequency, high-amplitude sea-level cycles which characterized the Quaternary Period.

SUMMARY

An internally-consistent, three-dimensional stratigraphic framework has been established for the inner continental shelf area lying between New and Mason Inlets along the northeastern limb of the Cape Fear cuspate foreland. The stratigraphic framework is based on the analysis of 119 km of high-resolution seismic reflection profiles and subsequent correlations to previously described vibracore and borehole sections.

Three seismic sequences were defined by tracing and mapping two unconformities (α and β_1) throughout the subbottom stratigraphic framework provided by the seismic network. The mapped seismic sequences and unconformities, in ascending order, are as follows: K_{pd}, a Late Cretaceous sequence correlative to the Peedee Formation; unconformity α, an erosional discontinuity surface; E_{ch}, a sequence equivalent to the middle Eocene Castle Hayne Formation; unconformity β_1, a downlap surface which also truncates underlying stratigraphies; and O_{rb}-A, an early Oligocene sequence correlative to the lower portion of the River Bend Formation. Of these three seismic sequences, only the early Oligocene section crops out on the sea floor in the surveyed area.

The Oligocene O_{rb}-A sequence is unconformably overlain by several other mapped stratigraphic units. Plio-Pleistocene valley-fill (PP_{vf}) lithosomes are generally confined to incised valleys cut 20 to 25 meters into the Oligocene section. Four significant northwest-southeast trending PP_{vf} channels were mapped in the survey area. Four Quaternary lithosomes unconformably overlie the Paleogene sequences and the PP_{vf} channels. The Quaternary units include a lower shoreface lithosome (LSL), linear shoreface-attached shoals (LSAS), inner shelf sand shoals (ISSS), and paleofluvial channel-fill (PFCF). Most of these lithosomes are presently being eroded across the shoreface/inner shelf boundary. Only the lower portions of the PFCF lithosomes seem to have a high potential for preservation.

ACKNOWLEDGEMENTS

Partial funding for this work has been provided to the North Carolina Geological Survey through an agreement between the U. S. Department of the Interior, Minerals Management Service (MMS) and the Continental Margins Committee of the Association of American State Geologists (AASG). This agreement is administered for MMS by the University of Texas, Bureau of Economic Geology. The MMS-AASG cooperative agreement covering work reported herein is number 14-12-0001-30497; the subagreement number is 30497-NC. The remaining resources were provided by the participating research organizations through in-kind services.

We thank the Department of Marine, Earth, and Atmospheric Sciences at North Carolina State University for logistical support; Steven L. Dooley, Tom Cornwell, and Charlotte Kelchner for their expertise in digitizing maps and interpreted seismic data; and John Nickerson and Richard Dentzman of the North Carolina Geological Survey Coastal Plain Office for help in preparing the illustrations. Reviews by James A. Dockel, Paul Gayes, John Nickerson, Larry Zarra, Charles Gardner, and Al Hine significantly improved this report.

REFERENCES CITED

Baum, G.R., Harris, W.B., and Zullo, V.A., 1978, Stratigraphic revision of the exposed middle Eocene to lower Miocene formations of North Carolina: Southeastern Geology, v. 20, p. 1-19.

Blackwelder, B.W., MacIntyre, I.G., and Pilkey, O.H., 1982, Geology of the continental shelf, Onslow Bay, North Carolina, as revealed by submarine outcrops: American Association of Petroleum Geologists Bulletin, v. 66, p. 44-56.

Blow, W.H., 1969, Late middle Eocene to Recent planktic foraminiferal biostratigraphy, *in* Bronnimann, P., and Renz, H.H., editors, Proceedings of the First International Conference on Planktonic Microfossils, Geneva, 1967: Leiden, Netherlands, E. J. Brill, v. 1, p. 199-422.

Buffler, R.T., Watkins, J.S., and Dillon, W.P., 1979, Geology of the offshore Southeastern Georgia Embayment, U. S. Atlantic continental margin, based on multichannel seismic reflection profiles, *in* Watkins, J.S., Montadert, L., and Dickerson, P.W., editors, Geologic and Geophysical Investigations of Continental Margins: American Association of Petroleum Geologists Memoir 29, p. 11-25.

Buffler, R.T., Shaub, F.J., Huerta, R., Ibrahim, A.B.K., and Watkins, J.S., 1981, A model for the early evolution of the Gulf of Mexico basin: *Oceanologica Acta*, v. 3, p. 129-136.

DuBar, J.R., Johnson, H.S., Thom, B.G., and Hatchell, W.O., 1974, Neogene stratigraphy and morphology, south flank of Cape Fear arch, North and South Carolina, *in* Oaks, R. Q., and DuBar, J. R., editors, Post Miocene Stratigraphy, Central and Southern Atlantic Coastal Plain: Logan, Utah, Utah State University Press, p. 139-173.

Ebeniro, J.O., O'Brien, W.P., and Schaub, F.J., 1986, Crustal structure of the south Florida platform, eastern Gulf of Mexico: an ocean-bottom seismograph refraction study: Marine Geophysical Researches, v. 8, p. 363-382.

Grosz, A.E., Hoffman, C.W., Gallagher, P.E., Reid, J.C., and Hathaway, J.C., 1990, Heavy-mineral resource potential of the Atlantic Continental Shelf offshore of North Carolina: a reconnaissance study: North Carolina Geological Survey Open-File Report 90-3, 58 p.

Grow, J.A., and Markle, R.G., 1977, IPOD-USGS multichannel seismic reflection profile from Cape Hatteras to the Mid-Atlantic Ridge: Geology, v. 5, p. 625-630.

Grow, J.A., Mattick, R.E., and Schlee, J.S., 1979, Multichannel seismic depth sections and interval velocities over the outer continental shelf and upper continental slope between Cape Hatteras and Cape Cod, *in* Watkins, J.S., Montadert, L., and Dickerson, P.W., editors, Geological and geophysical investigations of continental margins: American Association of Petroleum Geologists Memoir 29, p. 65-83.

Harris, W.B., 1975, Stratigraphy, petrology, and radiometric age (upper Cretaceous) of the Rocky Point Member, Peedee Formation, North Carolina [Ph.D. dissertation]: Chapel Hill, University of North Carolina-Chapel Hill, 189 p.

Harts, S.H., 1992, Sequence stratigraphy of undescribed lower Oligocene strata in Onslow County, North Carolina [abstract]: Geological Society of America Abstracts with Programs, v. 24, n. 2, p. 20.

Harris, W.B., Zullo, V.A., and Laws, R.A., 1993, Sequence Stratigraphic Analysis of Paleocene and Eocene Strata, Long Bay, NC [abstract]: Geological Society of America Abstracts with Programs, v. 25, n. 4, p. 21.

Hazel, J.E., Bybell, L.M., Edwards, L.E., Jones, G.D., and Ward, L.W., 1984, Age of the Comfort Member of the Castle Hayne Formation, North Carolina: Geological Society of America Bulletin, v. 95, p. 1040-1044.

Hine, A.C., and Riggs, S.R., 1986, Geologic framework, Cenozoic history, and modern processes of sedimentation on the North Carolina continental margin, *in* Textoris, D.A., editor, SEPM Field Guidebooks, Southeastern United States, Third Annual Mid-year Meeting: Society Economic Paleontologists and Mineralogists, p. 129-194.

Hine, A.C., and Snyder, S.W., 1985, Coastal lithosome preservation: evidence from the shoreface and inner continental shelf off Bogue Banks, North Carolina: Marine Geology, v. 63, p. 307-330.

Hoffman, C.W., Gallagher, P.E., and Zarra, Larry, 1991, Stratigraphic framework and heavy-mineral resource potential of the inner continental shelf, Cape Fear area, North Carolina: first interim progress report: North Carolina Geological Survey Open-File Report 91-3, 31 p

Imbrie, J., Hays, J.D., Martinson, D.G., McIntrye, A., Mix, A.C., Morely, J.J., Pisias, N.G., Prell, W.L., and Shackleton, N.J., 1984, The orbital theory of Pleistocene climate: Support from a revised chronology of the marine $\delta^{18}O$ record, *in* Berger, A.L., Imbrie, J., Hays, J., Kukla, G., Saltzman, B., editors, Milankovitch and Climate, Part I: Hingham, Massachusettes, Dordrecht (D. Reidel), p. 269-305.

Jones, G.D., 1983, Foraminiferal biostratigraphy and depositional history of the middle Eocene Rocks of the Coastal Plain of North Carolina: North Carolina Geological Survey Section Special Publication 8, 80 p.

Loutit, T.S., Hardenbol, J., Vail, P.R., and Baum, G.R., 1988, Condensed sections: the key to age dating and correlation of continental margin sequences, *in* Wilgus, C.K, Hastings, B.S., Kendall, C.G.St. C., Posamentier, W.W., Ross, C.A., and Van Wagoner, J.C., editors, Sea-Level Changes: An Integrated Approach: Society of Economic Paleontologists and Mineralogists Special Publication No. 42, p. 183.

Matteucci, T.D., 1984, High-resolution seismic stratigraphy of the North Carolina continental margin -- the Cape Fear region: sea-level cyclicity, paleobathymetry, and Gulf Stream dynamics [M. S. Thesis]: St. Petersburg, Florida, University of South Florida, 100 p.

Mearns, D.L., 1986, Continental shelf hardbottoms in Onslow Bay, North Carolina: their distribution, geology, biological erosion and response to Hurricane Diana, September 11-13, 1984 [M. S. Thesis]: St. Petersburg, Florida, University of South Florida, 150 p.

Meisburger, E.P., 1977, Sand Resources on the inner Continental Shelf of the Cape Fear region, North Carolina: U.S. Army Corps of Engineers, Coastal Engineering Research Center Technical Paper 77-11, 20 p.

Meisburger, E.P., 1979, Reconnaissance geology of the inner Continental Shelf, Cape Fear region, North Carolina: U.S. Army Corps of Engineers, Coastal Engineering Research Center Technical Paper 79-3, 135 p.

Meisburger, E.P., 1981, A Cretaceous-Tertiary depositional sequence in the submerged Coastal Plain off North Carolina: Southeastern Geology, v. 22, p 1-5.

Mitchum, R.M., Vail, P.R., and Thompson, S., 1977, Seismic stratigraphy and global changes in sea level, Part 2: The depositional sequence as a basic unit for stratigraphic analysis, *in* Payton, C.E., editor, Seismic stratigraphy - applications to hydrocarbon exploration: American Association of Petroleum Geologists Memoir 26, p. 53-62.

Moore, R.C., 1957, Modern Methods in Paleoecology: American Association Petroleum Geologists Bulletin 41, p. 1787-1789.

North Carolina Geological Survey, 1985, Geologic Map of North Carolina, North Carolina Geological Survey, Raeigh, 1 sheet, scale 1:500,000.

Pilkey, O.H., 1963, Heavy minerals of the U. S. South Atlantic continental shelf and slope: Geological Society of America Bulletin, v. 74, p. 641-648.

Popenoe, Peter, 1985, Cenozoic depositional and structural history of the North Carolina margin from seismic-stratigraphic analysis, *in* Poag, C.W., editor, Geologic evolution of the United States Atlantic margin: New York, Van Nostrand Reinhold Company Incorporated, p. 125-187.

Riggs, S.R., Snyder, S.W., Snyder, S.W., and Hine, A.C., 1990, Stratigraphic framework for cyclic deposition of Miocene sediments in the Carolina phosphogenic province, *in* Burnett, W.C., and Riggs, S.R., editors, Neogene to Modern phosphorites: Phosphate Deposits of the World, v. III, chapter 29, Cambridge University Press, Cambridge, England, p. 381-395.

Riggs, S.R., Lewis, D.W., Scarborough, A.K. and Snyder, S.W., 1982, Cyclic deposition of the upper Tertiary phosphorites of the Aurora Area, North Carolina, and their possible relationship to global sea level fluctuations: Southeastern Geology, v. 23, p. 189-204.

Sheridan, R.E., Drake, C.L., Nafe, J.E., and Hennion, J., 1966, Seismic-refraction study of the continental margin east of Florida: American Association of Petroleum Geologists Bulletin, v. 50, p. 1972-1991.

Slowey, N.C., Neumann, A.C., and Baldwin, K.C., 1989, Seismic expression of Quaternary climatic cycles in the peri-platform carbonate ooze of the northern Bahamas: Geological Society of America Bulletin, v. 101, p. 1563-1573.

Snyder, S.W., 1982, Seismic stratigraphy within the Miocene Carolina phosphogenic province: chronostratigraphy, paleotopographic controls, sea-level cyclicity, Gulf Stream dynamics, and the resulting depositional framework [M.S. thesis]: Chapel Hill, University of North Carolina-Chapel Hill, 183 p.

Snyder, S.W., 1994, Miocene sea-level cyclicity: frequency and amplitude estimates from the Carolina Platform [Ph.D. dissertation]: St. Petersburg, Florida, University of South Florida, 878 p.

Snyder, S.W., Hine, A.C., and Riggs, S.R., 1982, Miocene seismic stratigraphy, structural framework, and global sea level cyclicity: Southeastern Geology, v. 23, p. 247-266.

Vail, P.R., 1986, Seismic stratigraphy interpretation using sequence stratigraphy: *in* Bally, A.W., editor, Atlas of Seismic Stratigraphy: AAPG Studies in Geology No. 27, v. 1, p. 1-10.

Vail, P.R., Hardenbol, J., and Todd, R.G., 1984, Jurassic unconformities, chronostratigraphy and sea-level changes from seismic stratigraphy and biostratigraphy: Third Annual Conference, Gulf Coast Society and Society of Economic Paleontologists and Mineralogists, Proceedings, p. 347-364.

Van Wagoner, J.C., Posamentier, H.W., Mitchum, R.M., Vail, P.R., Sarg, J.F., Loutit, T.S., and Harbendol, J., 1988, An overview of the fundamentals of seismic stratigraphy and key definitions, *in* Wilgus, C.K, Hastings, B.S., Kendall, C.G.St. C., Posamentier, W.W., Ross, C.A., and Van Wagoner, J.C., editors, Sea-Level Changes: An Integrated Approach: Society of Economic Paleontologists and Mineralogists Special Publication No. 42, p. 39-45.

Ward, L.W., Lawrence, D.R., and Blackwelder, B.W., 1978, Stratigraphic revision of the middle Eocene, Oligocene, and lower Miocene—Atlantic Coastal Plain of North Carolina: U.S. Geological Survey Bulletin 1457-F, 23 p.

Wheeler, H.E. and Mallory, V.S., 1956, Factors in Lithostratigraphy: American Association of Petroleum Geologists Bulletin 40, p. 2711-2723.

Wheeler, W.H., and Curran, H.A., 1974, Relation of Rocky Point Member (Peedee Formation) to Cretaceous-Tertiary boundary in North Carolina: American Association of Petroleum Geologists Bulletin 58, p. 1751-1757.

Zarra, Larry, 1991, Subsurface stratigraphic framework for Cenozoic strata in Brunswick and New Hanover Counties, North Carolina: North Carolina Geological Survey Information Circular 27, 1 sheet.

Zullo, V.A., and Harris, W.B., 1987, Sequence stratigraphy, biostratigraphy, and correlation of Eocene through lower Miocene strata in North Carolina: Cushman Foundation for Foraminiferal Research Special Publication 24, p. 197-214.